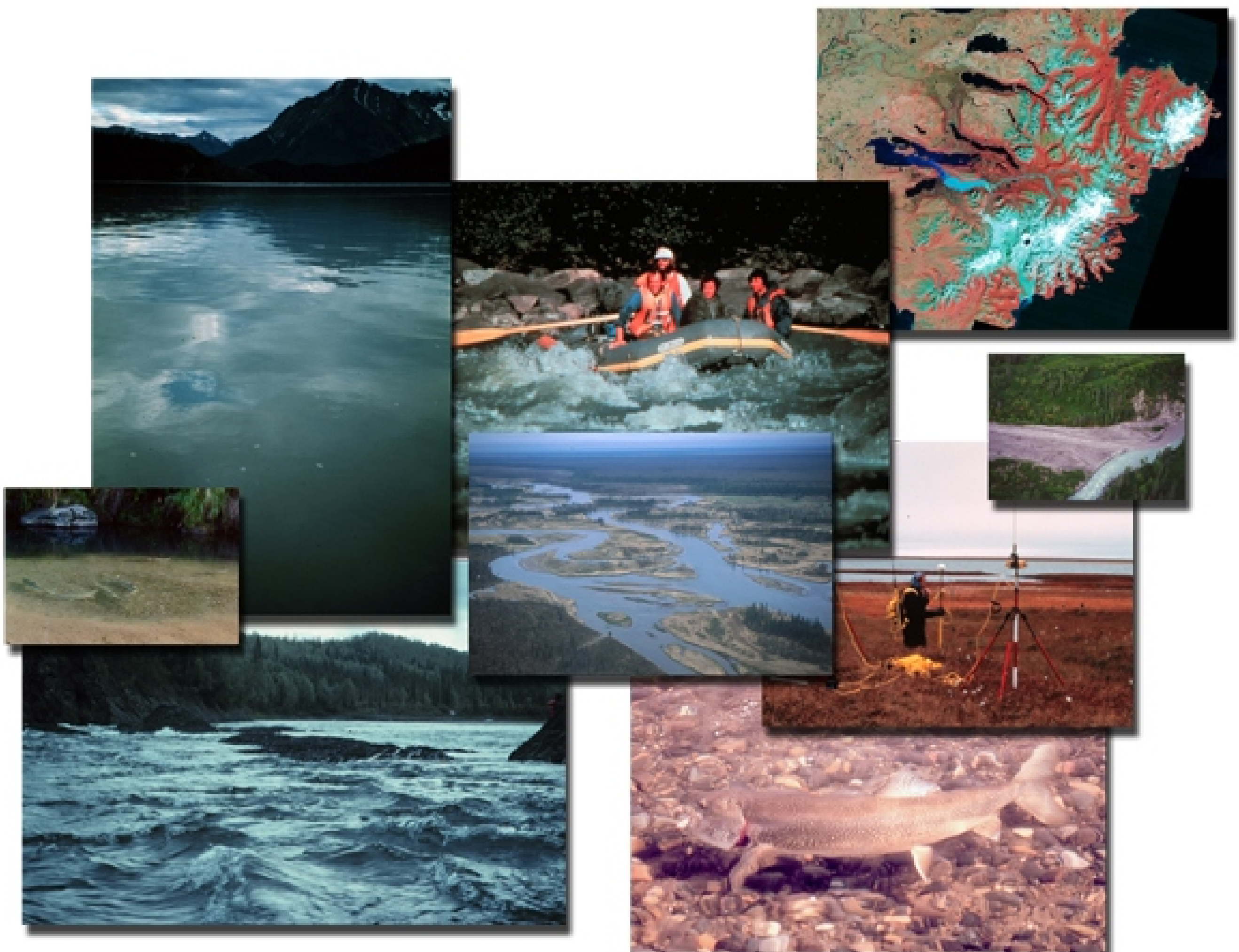
National Park Service - Southwest Alaska Network
Inventory & Monitoring Program

Freshwater Monitoring - Scoping Workshop
Southwest Alaska Network

November 4-6, 2002
Cooper Landing, Alaska



Photos by Nancy Deschu and NPS

Southwest Alaska Network Inventory & Monitoring Program
2525 Gambell Street
Anchorage, Alaska 99503

Freshwater Monitoring – Scoping Workshop
Long-term Vital Signs Monitoring Program
Southwest Alaska Network
4-6 November, 2002

Workshop Purpose

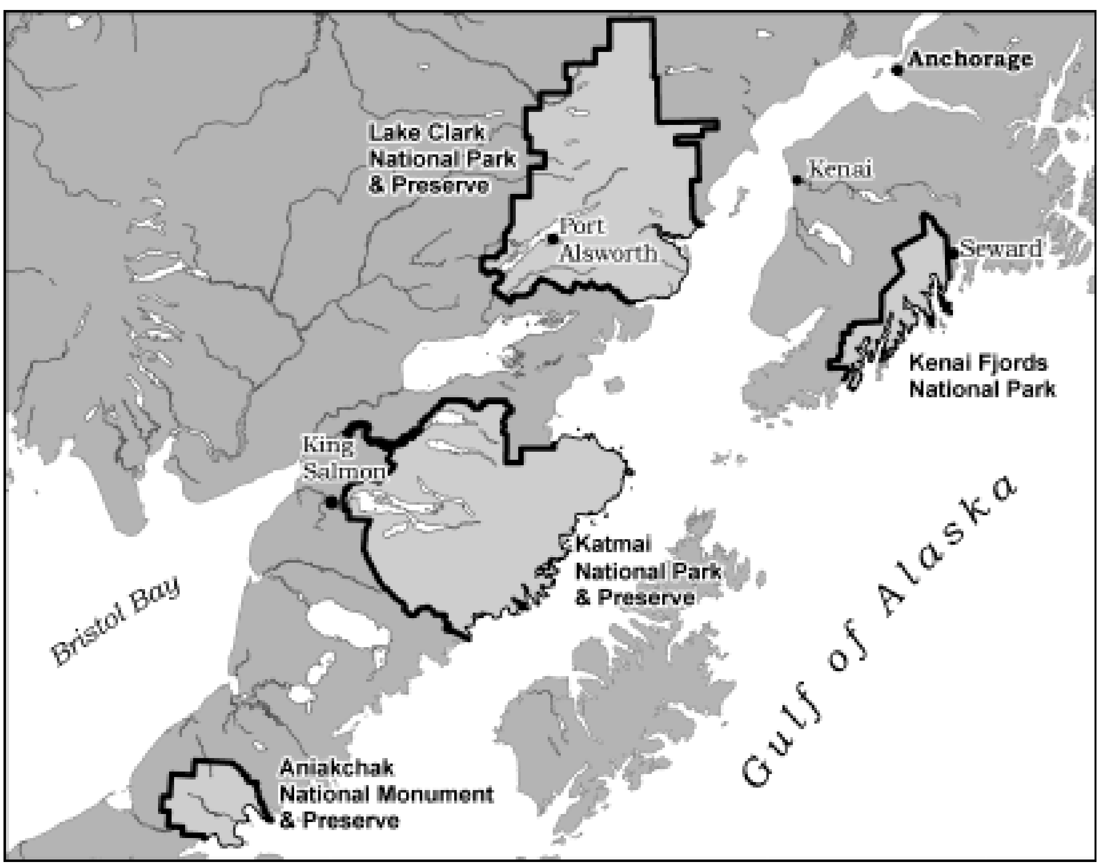
Provide a forum for National Park Service resource managers and scientists to discuss ideas and options for building a statistically sound, ecologically-based, management-relevant, and affordable freshwater ecosystem monitoring program at Southwest Alaska Network (SWAN) Park units.

Workshop Objectives

1. Review/Refine Conceptual Ecosystem Models and Monitoring Questions

2. Identify Drivers of Change and Why it is Important to Understand Them

3. Identify Candidate Attributes to Monitor that Provide Reliable Signals about Ecosystem Condition



Draft Agenda
Freshwater Monitoring - Scoping Workshop
Southwest Alaska Network
4-6 November, 2002

Monday, 4 November

6:00 PM. Dinner at Kenai Princess Wilderness Lodge, Mile 47.7 Sterling Highway

7:30-9:00 PM Evening Session

Southwest Alaska Network Lakes and Rivers Slide Presentation

Initial comments from invited guests on contents of the Scoping Workshop Notebook and other suggestions for the 2-day workshop (up to 15 min each)

Joe Margraf, AK Cooperative Fish & Wildlife Research Unit
Jim Larson, U.S. Fish and Wildlife Service
John Magnuson, University of Wisconsin
Robert Stallard, U.S. Geological Survey-WRD

9:00 PM. Adjourn

Tuesday, 5 November

8:00-8:30 AM Introduction

Vital Signs Monitoring Program in Alaska National Park Units
Sara Wesser, Regional Inventory & Monitoring Coordinator (10 min)

Water Quality Monitoring – Core parameters
Nancy Deschu, Regional Hydrologist, NPS-Alaska (10 min)

Workshop Procedures and Guidelines.
Alan Bennett, Coordinator, Southwest Network, Inventory and Monitoring Program (10 min)

8:30-10:00 AM Session 1. Review and Refine Conceptual Ecosystem Models & Monitoring Questions. Phil North-EPA, Facilitator

Break (15 min)

10:15-12:00 AM. Session 2. Identify drivers of change and candidate attributes to monitor in lakes. Phil North-EPA, Facilitator

12:00-1:30 PM. Lunch

1:30-3:15 PM Session 2 continues (lakes).

Break

3:30-5:00 PM Session 2 continues (lakes).

6:00 PM. Dinner

Wednesday, November 6

8:00-9:45 AM. Session 3. Identify drivers of change and candidate attributes to monitor in rivers. Phil North-EPA, Facilitator

Break

10:00-12:00 AM. Session 3 continues (rivers).

12:00-1:30 PM. Lunch

1:30-3:00 PM. Wrap-up Discussions and closing comments and suggestions from invited guests (15 min each)

3:00 PM. End of Workshop

NOTEBOOK CONTENTS

Sections of this notebook represent a skeletal format of what will eventually become the Southwest Networks *Conceptual Foundation for Monitoring*. The goals, monitoring questions, conceptual models, and concepts and will be refined during successive workshops and peer review. Ultimately, this information will form the basis for drafting a long-term monitoring plan. In addition to providing background information, our intention in producing this notebook is for it to play a in capturing your suggestions, ideas, and comments. Notebooks will be collected at the end of the workshop but returned to participants once we have gone though them and captured any remarks or suggestions that you have placed in the margins.

BACKGROUND- Describes the rationale behind the National Park Service's (NPS) multi-phase effort to launch a long-term "vital signs" monitoring program in 270 national park units. Provides an overview of the Southwest Alaska Network's organization, planning approach, design considerations for monitoring freshwater systems, and the role of this workshop. Other background information includes a brief overview and summary of natural resource management issues and on-going monitoring for each park unit.

GOALS- Outlines the relationship between National Park Service Mandates, Network Park and Preserve Mandates, and the NPS Service-wide goals for monitoring. It identifies the overall Southwest Alaska network programatic goal and the specific goals and questions for monitoring freshwater ecosystems. This workshop will play a pivotal role in assembling information that the Network will use to refine these monitoring questions and objectives. Finally, it defines some framework parameters that the Technical Commmittee considers crucial in designing the program.

MODELS- This section contains a series of draft conceptual models of SWAN freshwater ecosystems. These models are based on information contained in network park Resource Management Plans, Technical Committee discussions, and review of published and unpublished reports on freshwater ecosystems in northern lattitudes. Refinement of these models or creation of alternative models is a task for workshop participants.

PARTNERSHIPS- Identifies prospective partners and cooperators in monitoring of freshwater ecosystems within the SWAN.

ECOLOGICAL PROFILES- Draft freshwater ecological profiles of each park and preserve; a selected bibliography; and maps depicting ecoregions, drainage basins, land status, and selected physical and biological data layers available for SWAN park units

Invited Participants
Freshwater Monitoring - Scoping Workshop

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Rationale For Long-term Monitoring In Southwest Alaska National Park Units And The Role Of This Workshop

National Park Service Inventory and Monitoring Program-
The National Park Service has implemented a strategy designed to standardize natural resource inventory and monitoring on a programmatic basis throughout the agency. The effort was undertaken to ensure that the approximately 270 park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. The national strategy consists of a framework having three major components:

(1) completion of basic natural resource inventories in support of future monitoring efforts;
(2) creation of experimental Prototype Monitoring Programs to evaluate alternative monitoring designs and strategies; and
(3) implementation of operational monitoring of selected parameters (i.e. "vital signs") in all natural resource parks.

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to protect and manage parks. National Park managers across the country are confronted with increasingly complex and challenging issues, and managers are increasingly being asked to provide scientifically credible data to defend management actions. Many of the threats to park resources, such as invasive species and air and water pollution, come from outside of the park boundaries, requiring an ecosystem approach to understand and manage the park's natural resources.

A long-term ecosystem monitoring program is necessary to enable managers to make better informed management decisions, to provide early warning of abnormal conditions in time to develop effective mitigation measures, to convince other agencies and individuals to make decisions benefiting parks, to satisfy certain legal mandates, and to provide reference data for relatively pristine sites for comparison with data collected outside of parks by other agencies. The overall purpose of monitoring is to develop broadly based, scientifically sound information on the current status and long term trends in the composition, structure, and function of the park ecosystem. Use of monitoring information will increase confidence in manager's decisions and improve their ability to manage park resources.

National Park Service policy and recent legislation (National Parks Omnibus Management Act of 1998) requires that park managers know the condition of natural resources under their stewardship and monitor long-term trends in those resources in order to fulfill the NPS mission of conserving parks unimpaired. The following laws and management policies provide the mandate for inventorying and monitoring in national parks:

The mission of the National Park Service is:
"*...to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations*" (National Park Service Organic Act, 1916).

"*The Secretary shall undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources. The monitoring program shall be developed in cooperation with other Federal monitoring and information collection efforts to ensure a cost-effective approach*" (National Parks Omnibus Management Act of 1998)

"*Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions*" (2001 NPS Management Policies).

Southwest Alaska Network-
In Alaska, national park units have been assigned to 4 inventory and monitoring networks (see maps). The networks were based on ecological similarity and proximity. The southwest Alaska network (SWAN) consists of 5 units:

(1) Katmai National Park and Preserve (KATM),
(2) Alagnak Wild River (ALAG),
(3) Aniakchak National Monument and Preserve (ANIA),
(4) Lake Clark National Park and Preserve (LACL) and
(5) Kenai Fjords National Park (KEFJ).

The timeline for designing the Southwest Alaska Network monitoring program and writing a monitoring plan is approximately 2 years (Fig 1). Natural resources staff from each of the parks and staff from the NPS Alaska Support Office comprise the core planning team, known as the *Technical Committee* (TC). This committee is chaired by the Network Coordinator and reports to the Park Superintendents and Regional I&M Coordinator.

The Southwest Alaska Network began operations in 2000 with the planning of biological inventories for vascular plants, freshwater fish, and small mammals. The target objective of biological inventories is to document the occurrence of 90% of the expected species in network parks. Baseline knowledge is weak for SWAN parks, and these inventories represent the first systematic efforts to document species occurrence for these taxa in these parks. Biological inventories will occur over four years with data analysis and final reports scheduled for 2005.

Planning for long-term monitoring began in January 2002. The planning process is built around a series of mini-scoping workshops where the Technical Committee and scientists from other agencies collaborate in reviewing our current state of knowledge, identifying factors affecting park ecosystems, and identifying candidate attributes to monitor. The Freshwater Aquatic Workshop is the second in a series of such workshops to be held between August and December, 2002. In early 2003, a multidisciplinary workshop will focus on developing an integrative and feasible sampling framework for biotic and abiotic resources in all systems (coastal, freshwater, and terrestrial).

The first mini-scoping workshop was for coastal resources and was held in late August 2002. The meeting format proved highly successful in generating useful discussion about Southwest Alaska Network parks coastal ecosystems and monitoring strategies. We hope to build on that process with our freshwater session and successive workshops.

In planning for long-term monitoring, it is useful to have some idea of the financial and logistic constraints. Beginning in 2004, the total projected annual operating budget for the SWAN monitoring program will be 1.4 million dollars. All program costs including administration and salaries, data management, and operational monitoring must be supported by this budget. Core permanent employees of each network may include the Coordinator, Biometrician, and Data Manager. Hence, it is reasonable to assume that the operating budget for this network will be roughly 1.0 million dollars of which approximately 1/3 ($350,000) will be directed at freshwater systems.

Design of Freshwater Monitoring to Meet Network Goals-
Southwest Alaska Network Parks contains some of the grandest freshwater resources in the National Park System. This includes the two largest lakes, Naknek Lake and Lake Clark, and thousands of miles of rivers including five designated “Wild Rivers.” Approximately 432,000 acres (12%) of Katmai is occupied by surface water. Network Parks also contain 1.9 million acres of freshwater wetlands including riverine, palustrine, and lacustrine wetland types.

Clearly, it is not possible to monitor every physical, chemical, and biological attribute across the full breadth of freshwater systems in this 10 million-acre network. Consequently, the Technical Committee has decided that the initial focus of freshwater monitoring in SWAN will be directed at large lake and river systems. Other freshwater systems such as riparian wetlands, montane wetlands, beaver ponds, and small tundra lakes may be monitored in future phases of the program. We anticipate that workshop discussions will venture into these systems because of hydrologic connectivity, functional relationships, and biological interactions.

Our approach to long-term monitoring views lakes, rivers, and watersheds as interactive components of their environment.   Consequently, we will attempt to develop a "network-wide" understanding of lakes and rivers and how they are influenced by atmospheric, oceanic, hydrologic, and biotic processes.   This cross-discipline multi-scale approach is in contrast to historic limnological or biological surveys of network parks that focussed on individual lakes and rivers, and often for a singular purpose.

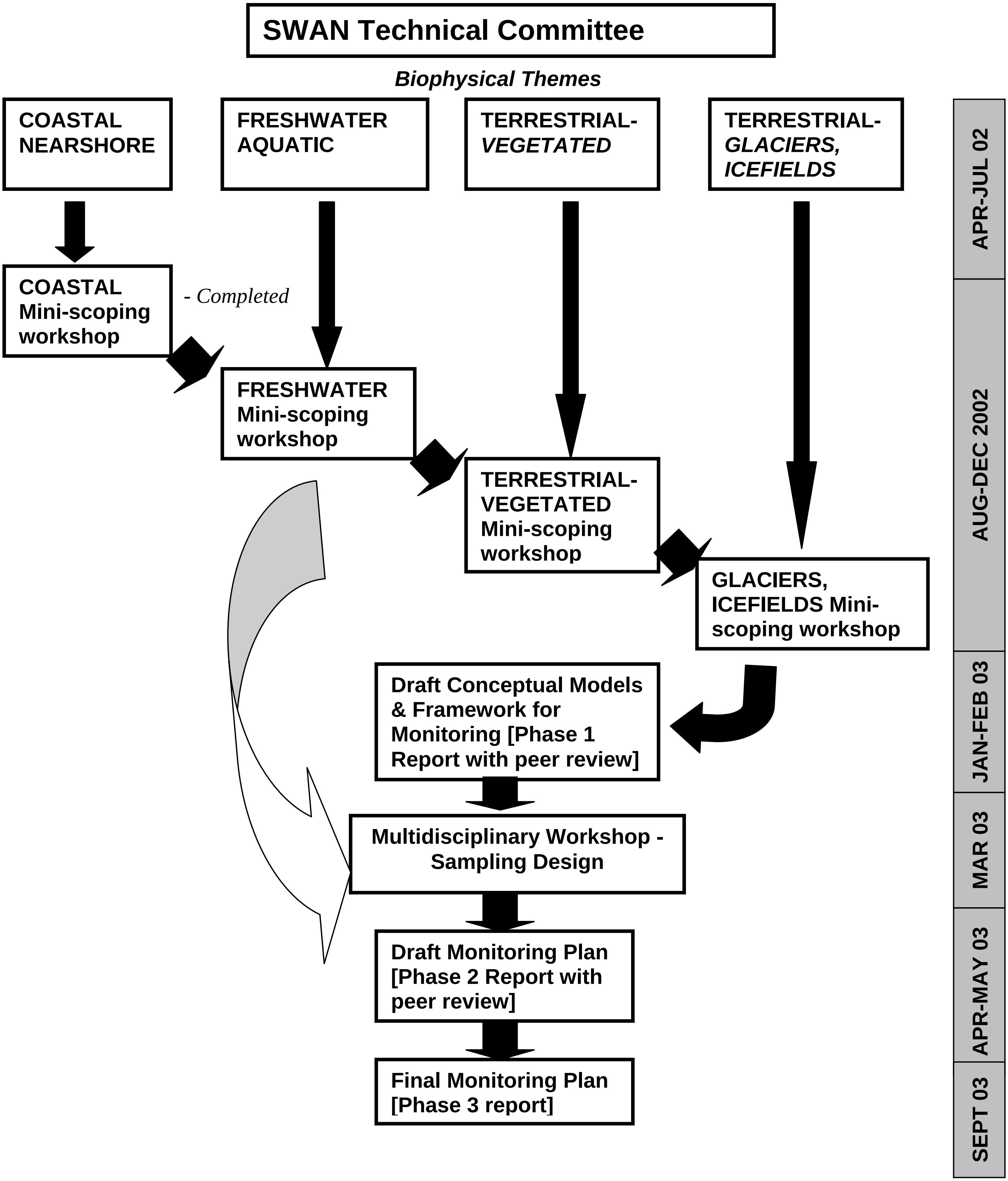
The workshop will focus on discussion of the freshwater ecosystems of Southwest Alaska Network parks, and on what can be learned from monitoring various attributes of these systems. Although not the focus of this workshop, design issues will likely surface. We would like to defer our design discussions until all the workshops have been held and specific monitoring objectives have been set. However, to help frame our discussions, we would like to provide our preliminary thoughts on this topic with respect to freshwater ecosystems.

Our design framework is likely to involve a nested strategy of monitoring primary and secondary sites, i.e., measure a "smaller" number of parameters on as many lakes and rivers as possible and measure a "larger" number of parameters on those that are most easily measured, ecologically interesting, or of greatest importance to park managers. For example, a site-intensive (primary lake) strategy may be attractive for Naknek Lake and Lake Clark because they are "nucleus" systems in their respective parks, have substantial historic databases, and are logistically within easy reach of park field stations. These lakes may serve as "flagship" sites that are well understood, have on-site facilities and instruments (e.g. automatic weather stations, deposition collectors), and are sites for specific process-related studies needed to refine models (e.g. hydrological processes, ice-cover dynamics, micropollutant bioaccumulation). Similarly, the Alagnak River may receive more intensive monitoring because of management issues surrounding its National Wild River designation.

The intent of monitoring secondary sites is to build upon primary sites to develop a network-wide or ecoregion understanding of "reference conditions" that take into account natural variability within and between systems over space and time. For example, patterns and distributions of pollutants, patterns and distribution of aquatic organisms, and fish population status. Monitoring of secondary sites will be expensive, logistically challenging and require careful selection of sample sites, meaningful attributes, and appropriate and cost-effective monitoring frequency.

It is important to acknowledge that the Central Alaska Network (CAN), which includes Denali, Wrangell-St. Elias, and Yukon-Charley Rivers, may focus their freshwater monitoring effort on small ponds and headwater stream ecosystems. The Central Alaska Network has contracted with WEST, Inc., a statistical consulting, for a sampling design framework for freshwater ecosystems, and the strategy that CAN develops may be exportable to SWAN and other networks. Another network that plans to invest considerable effort in aquatic monitoring include the North Coast and Cascades network in northwestern Washington.

Figure 1. Framework & Schedule for the Development of a Long-term Monitoring Plan - Southwest Alaska Network



Mandates Underlying the Need for Long-term Monitoring And Programmatic Goals

NPS Mandate:- " . .to preserve for the benefit, use, and inspiration of present and future generations . . ". .

SWAN Park and Preserve Mandates

Katmai National Park and Preserve- "for the protection of the ecological and other scientific values of Naknek lake and the existing monument….." "To protect habitats for, and populations of, fish and wildlife, including, but not limited to, high concentrations of brown/grizzly bears and their denning areas; to maintain unimpaired the water habitat for significant salmon populations; and to protect scenic, geological, cultural, and recreational features."

Alagnak National Wild River- "To protect and enhance the values which caused it to be included in said system…." These values are the river's outstandingly remarkable scenic, fish and wildlife, and recreation attributes. (ANILCA)

Aniakchak National Monument and Preserve- "To maintain the caldera and its associated volcanic features and landscape, including the Aniakchak River and other lakes and streams, in their natural state; To protect habitat for, and populations of, fish and wildlife, including, but not limited to, brown/grizzly bears, moose, caribou, sea lions, seals, and other marine mammals, geese, swans, and other waterfowl….." (ANILCA):

Lake Clark National Park and Preserve- "To protect the watershed necessary for the perpetuation of the red salmon fishery in Bristol Bay; To maintain unimpaired the scenic beauty and quality of portions of the Alaska Range and the Aleutian Range, including volcanoes, glaciers, wild rivers, lakes, waterfalls, and alpine meadows in their natural state; To protect habitats for and populations of fish and wildlife, including, but not limited to caribou, Dall sheep, brown/grizzly bears, bald eagles, and peregrine falcons." (ANILCA)

Kenai Fjords National Park- "To maintain unimpaired the scenic and environmental integrity of the Harding Icefield, its outflowing glaciers, and coastal fjords and islands in their natural state; and to protect seals, sea lions, other marine mammals, and marine and other birds and to maintain their hauling and breeding areas in their natural state, free of human activity which is disruptive to their natural processes." (ANILCA)

Protect and Manage Natural Resources

Maintain landscape features, ecosystems, communities, populations, trophic structure, and productivity within the historic bounds of natural variability

Understand Natural Resources and Ecosystem Dynamics

Conduct Resource Inventories

Conduct Long-term Monitoring

NPS Service-wide Vital Signs Monitoring Goals

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.

2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.

3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.

4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.

5. Provide a means of measuring progress towards performance goals

SWAN
Overall Network Goals:

I. Establish baseline reference conditions representing the current status of park and preserve ecosystems; and

II. Detect changes over time, particularly, any changes that are outside the natural variation in these baselines.

An overarching goal of the freshwater component of the monitoring program is to track and understand how aquatic communities and habitats respond to natural processes, and to be able to distinguish differences between human-induced disturbance effects to aquatic ecosystems and those caused by natural processes. Major natural disturbances affecting the Southwest Alaska Network include episodic floods, volcanic eruptions, earthquakes, geomorphic changes in stream channels and landforms, fire, wind, glacial activity, and insect infestations. Human-induced disturbances include alterations of air and water quality and quantity, habitat destruction or modification, and biological alterations (e.g. commercial, subsistence, and sport harvests of native species, non-native species introductions, logging, etc.).

Freshwater Ecosystem Monitoring Goals & Questions:

Goal I. Understand ecological relationships and long-term changes in the physical, chemical, and biotic features of large rivers and lakes.

- What are baseline water quality constituents associated with primary production, including dissolved oxygen, pH, nutrients, total suspended solids, chlorophyll-a, and total organic carbon and how are they changing temporally?
- How are the thermal dynamics of large lakes changing in relation to the duration or lack of winter ice cover, changes in seasonal runoff, and storm frequency/intensity?
- Are seasonal discharge regimes of snowmelt rivers shifting? (i.e., higher winter flows and lower spring and summer flows?)

Goal II. Understand how landscape, oceanic, and atmospheric processes interact with rivers, lakes, and wetlands to affect park resources that are ecological "keystones" or highly valued by stakeholders and visitors.

- How is lake food web structure and production to higher trophic levels changing in response to salmon abundance (marine-derived nutrients)?
- Are declining salmon populations having indirect effects on other organisms that make use of salmon at critical times in their life cycle?
- How is the quality of anadromous fish spawning habitat changing in relation to lake water levels, shoreline development?

<u>Goal III.</u> Understand the ways humans interact with aquatic ecosystems to affect physical and biotic components.

- Are atmospherically deposited or biotransported pollutants such as methyl mercury accumulating in lake sediments and resident biota and are there geographic gradients in their concentrations?
- Is fish community composition and structure changing in lakes and rivers where sport and subsistence fishing effort and harvest are increasing?

<u>Monitoring Framework Requirements*</u>

- Ecologically-based issues-oriented with emphasis on assessing long-term and <u>cumulative effects</u>, rather than short-term and isolated effects
- Incorporates work from multiple disciplines (e.g., biology, hydrology, geomorphology, and landscape ecology) and at multiple scales (e.g., coarser-grained network-scale, and finer-grained park-scale)
- Blends "top-down," integrative approach for characterizing ecological systems, with "bottom-up" understanding of ecosystem processes and functions
- Focuses on forces known to shape park ecosystems (natural disturbance, human use, climate, physiography, and biotic interactions) and on components that are sensitive to change

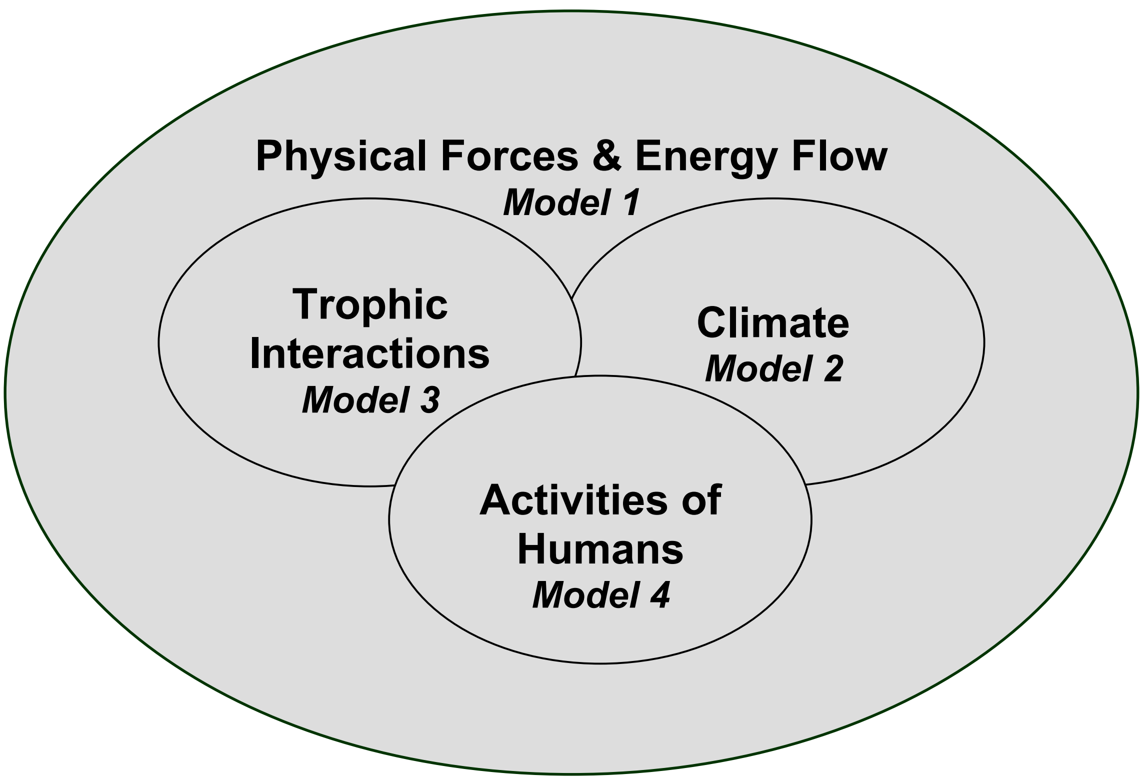
**Defined by SWAN Technical Committee*

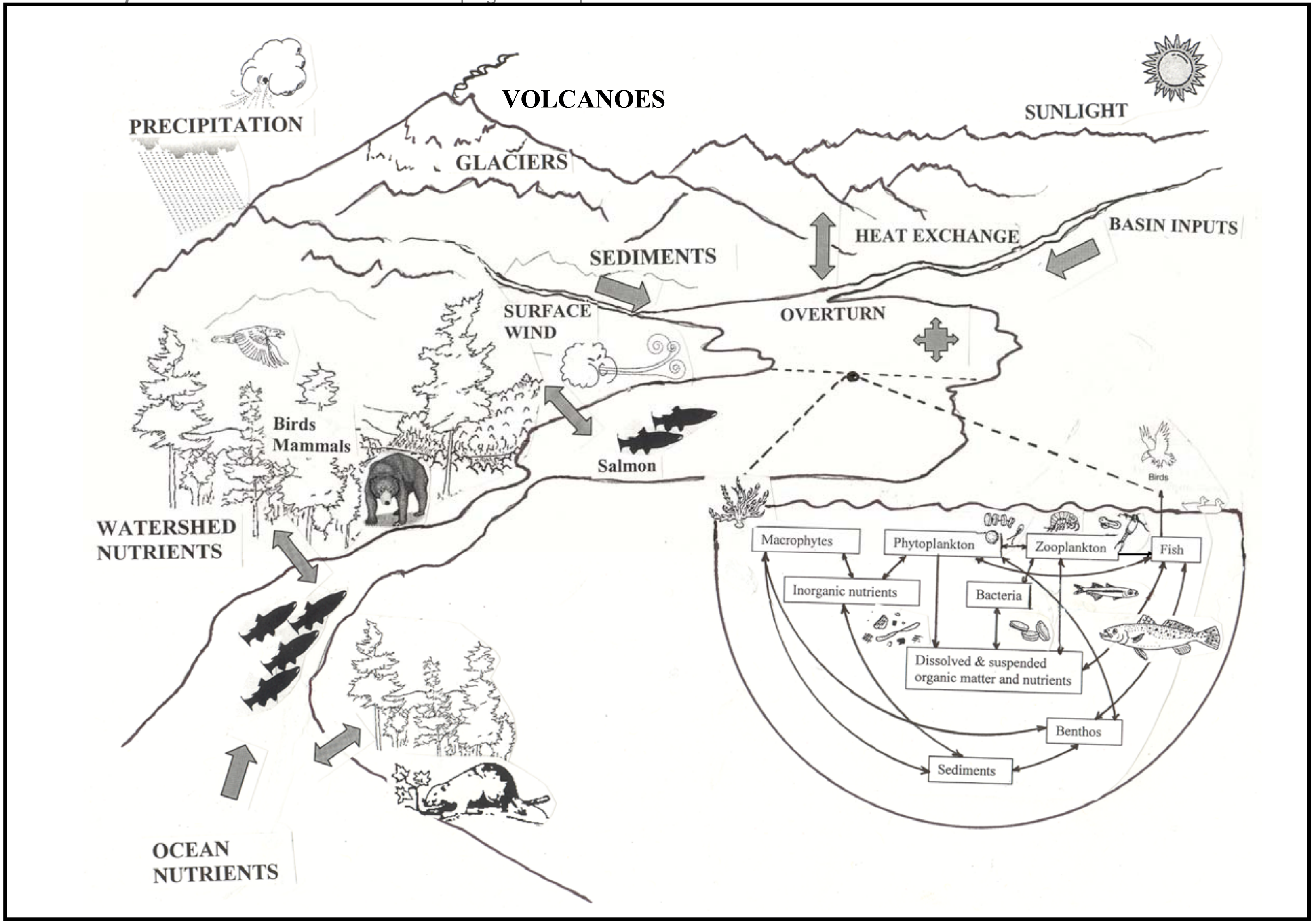
<u>Criteria for selection of attributes (“vital signs”) to monitor</u> (modified from Dale and Beyeler 2001)

- ***Be easily measured***. The attribute should be straightforward and relatively inexpensive to measure
- ***Wide distribution over an ecoregion, park unit or the network***
- ***Be sensitive to stresses on the system.*** Responsive to stresses placed on the system by human actions while also having limited and documented sensitivity to natural variation
- ***Respond to stress in a predictable manner.*** Have a known response to disturbances, human-induced stresses, and changes over time
- ***Have low variability in respons*e**. Attributes that have a small range in response to particular stresses allow for changes in the response value to be better distinguished from background variability
- ***Be integrative.*** The full suite of attributes provides a measure of coverage of the key gradients across the ecological systems (e.g. gradients across soils, vegetation types, temperature, space, time, etc.)
- ***Be anticipatory***. Signify an impending change in key characteristics of the ecological system

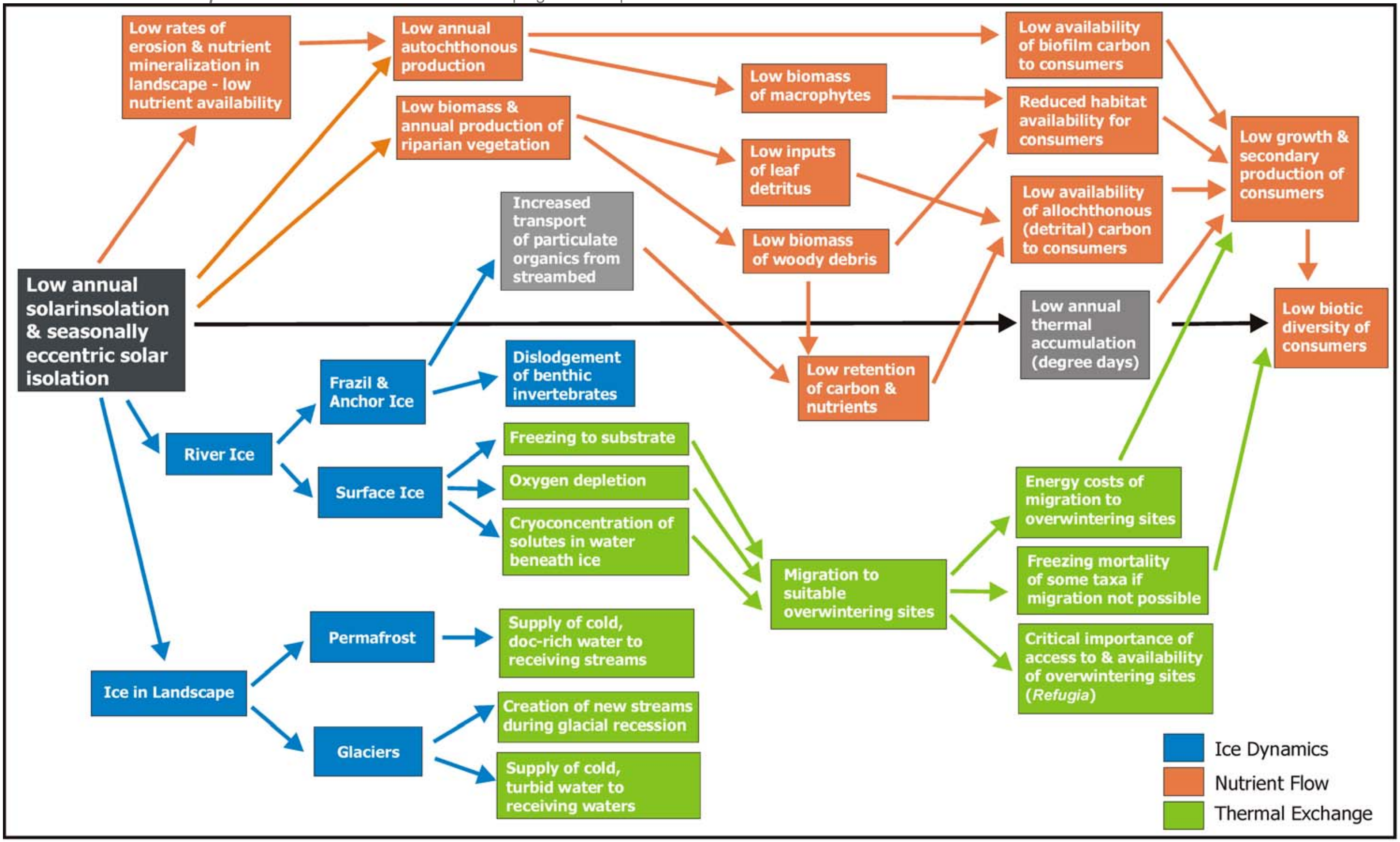
CONCEPTUAL MODELS
SWAN FRESHWATER ECOSYSTEMS

The SWAN conceptual models depict ecosystem structure, processes, and mechanistic relationships among biotic, abiotic, and anthropogenic components and linkages in a schematic format. Models were developed to help summarize our state of knowledge, assist in identifying important issues confronting freshwater ecosystems, and ultimately, to assist with selection of specific attributes to monitor. We used a series of hierarchical models to avoid producing one figure with an indecipherable amount of information on it. In some cases, we elected to use a pictorial format which is often more readily understood by both ecosystem scientists and park managers. Pictorial models are described in 'summaries' that follow the illustration and describe principles of the interactions involved.

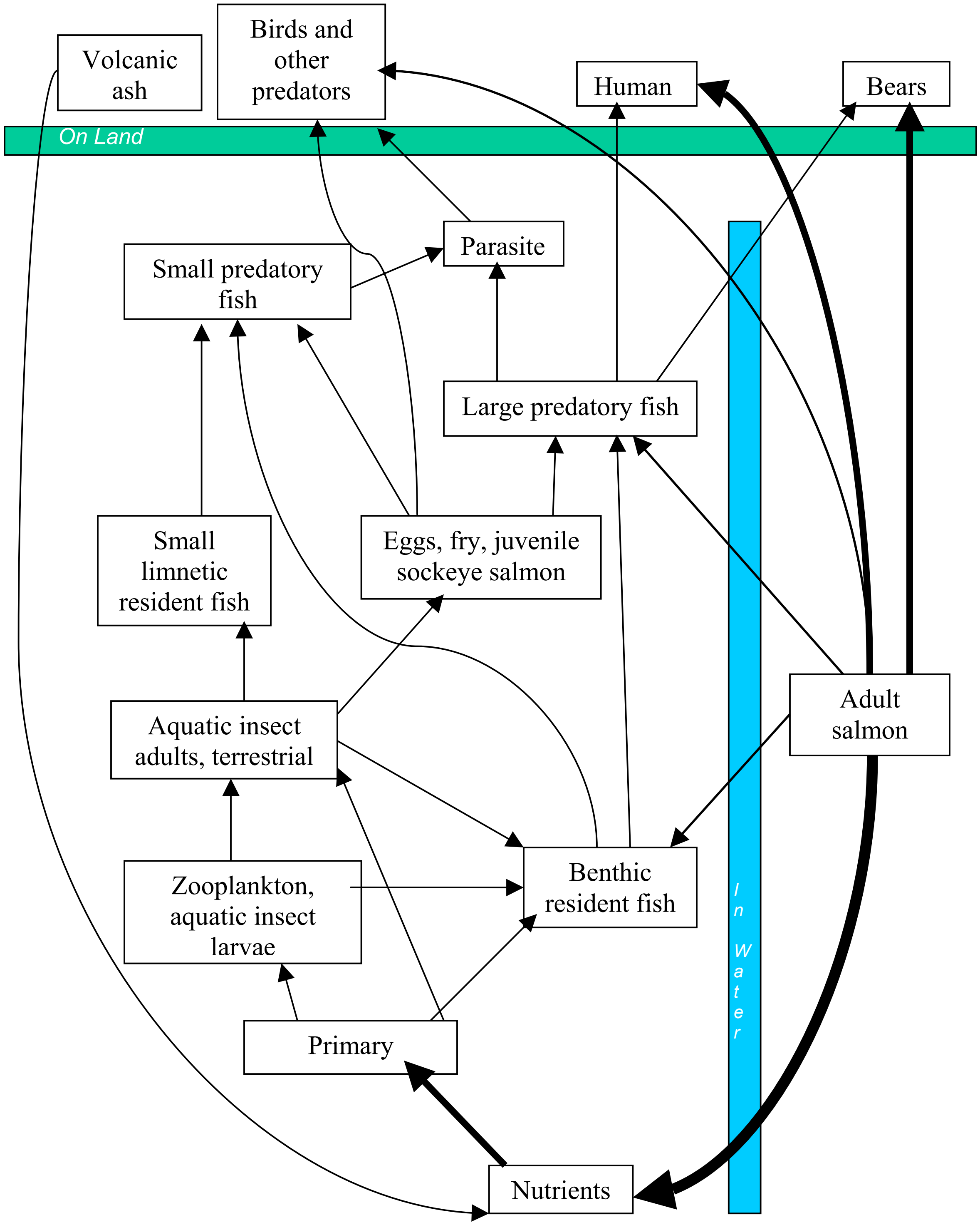




Model 1 . A conceptual view of the major **physical forces and pathways of energy and nutrient flow** between atmosphere, ocean, watersheds, and representative biotic communities in SWAN rivers and lakes. Atmospheric processes such as sunlight, precipitation, temperature, and wind control water movements and thermal dynamics. Glacial activity controls sedimentation patterns, water temperature, and rates of discharge. Salmon contribute large quantities of dissolved matter and nutrients to rivers, lakes, and riparian ecosystems. Nutrient transfer and other feedbacks between terrestrial plants and animals and freshwater systems affects primary and secondary productivity of both systems.



Model 2. Conceptual view of the effects of high latitude **climate** on running waters. Low sunlight and cold permeates the ecology of Alaska rivers. The model suggests that the direct consequences of high latitude on running water can be grouped into three broad categories: creation of ice in both aquatic and terrestrial systems, limited inputs and retention of inorganic nutrients and carbon, and thermal effects on rates of biological processes of aquatic organisms. Finally, the model depicts interactions among these direct effects that codetermine some characteristic features of consumers in Alaskan running waters: low biotic diversity and low growth and production (Milner and Oswood 1997).



Model 3. The influx of anadromous fishes dramatically affects the **trophic structure** of the freshwater community. Most salmon die after they spawn and their carcasses accumulate in streams and along lakeshores. A rich community of algae, fungi, and bacteria develops on the carcasses and populations of invertebrates increase. These invertebrates then serve as food for fish in the streams and lakes, including juvenile salmon. More surprising are the potential fertilizer effects of salmon carcasses on land. Bears and other carnivores commonly haul salmon, living or dead, onto stream banks and hundreds of yards into the forest. Eagles move carcasses into riparian areas and ravens and crows cache salmon bits in trees and under grass and rocks. Nutrients pass from the bodies of salmon into the soil and then into riparian vegetation and ultimately farther up the terrestrial food chain.

National Park Service - Southwest Alaska Network **Model 4: Human Activities - Freshwater Ecosystem Effects**

Inventory & Monitoring Program

Model 4 Description

Human activities can have both local and widespread effects on aquatic ecosystem processes and productivity. Roads, ATV routes, marinas and airstrips can destroy or change the physical characteristics of stream channels, lakeshores and wetlands. Disturbed ground cover and hydrologic changes can lead to turbidity and altered water chemistry while boat/floatplane wakes can erode riverbanks and lakeshores. Spills in or near waterbodies during fueling operations, fuel storage and transport, inadequate septic systems and landfills can contaminate ground- and surface waters, and may lead to eutrophication. Water diversion, large scale water use and hydroelectric development can disrupt natural hydrologic processes and affect fish movements. Lakeshore and riverbar gravel extraction destroy aquatic habitat and alter geomorphology. Fishing, rafting, camping and other recreational activities can deplete fish stocks and introduce toxins. Floatplanes moving between lakes can accidentally or intentionally introduce non-native fish, aquatic plants and aquatic invertebrates. Residential/community development, mining and logging intensify these effects both spatially and temporally, ultimately fragmenting or destroying habitat, changing ecosystem processes and modifying trophic interactions. Aquatic ecosystems are also vulnerable to changes in insolation and atmospheric deposition caused by global industrialization. Widespread effects could include altered water chemistry, increased incidence of genetic mutation/deformities and changes in water temperature. Climate change could cause glacial retreats and reduce surface water supply and cold water habitats. Hatchery fish compete and interbreed with native fish which degrades genetic diversity.

Outline for Workshop Discussions (Sessions 2 - 4)

SYSTEM: ***Lakes (primary & secondary)***

WHAT ARE THE MOST IMPORTANT AGENTS OF CHANGE IN FRESHWATER ECOSYSTEMS?

- Climate
- Physical Processes
- Chemical
- Biological Interactions
- Human Activities

WHAT ARE THE MOST IMPORTANT BIOTIC AND ABIOTIC FEATURES THAT WE SHOULD MONITOR?

- Climate
- Physical Processes
- Chemical
- Biological Interactions
- Human Activities

POTENTIAL PARTNERS:

SUGGESTED REFERENCES:

Potential Partners for Freshwater Monitoring
Southwest Alaska Network

National Park Service

Alaska I&M Networks and Regional Office

The four Alaska Networks and staff of the Alaska Regional Office have a unique opportunity to collaborate in monitoring freshwater systems. Collectively, they may function as a team and share professional expertise, monitoring protocols, and data management strategies.

National Park Service- Water Resources Division (WRD)

WRD is responsible for providing water resource management policy, planning, and operational support to NPS managers Servicewide. These services and assistance are provided either directly to parks, clusters, regions, centers, and Washington Office or in cooperation with other NPS organizational units, agencies, or entities.

Areas where WRD may partner with networks for monitoring include:

- modifying and developing methods and procedures for applied water resources management; and
- conducting projects and studies in support of water resource needs.

Other Federal Agencies

US Geological Survey-Biological Resources Division- Alaska Science Center

The Alaska Science Center is responsible for research trust lands and waters (including those of the National Park Service, Fish and Wildlife Service, Bureau of Land Management, and Minerals Management Service) and DOI trust species (including migratory birds, marine mammals, and anadromous fish) in Alaska, providing scientific information essential for resource management decisions. Four divisions of the Alaska Science Center support the objectives of SWAN: The Biological Research Division (BRD), Water Resources Division (WRD), Research Division (GRD), and the Mapping Division. The research division has been actively involved in studies of sockeye salmon in Lake Clark since 1997.

US Fish and Wildlife Service, Water Resource and Refuges (FWS)

http://alaska.fws.gov/water/Water_resources.htm
Monitoring:
Refuges and national parks share common water resource and fisheries management issues. FWS operates a network of stream discharge gages to quantify the occurrence and distribution of surface water on selected refuges within the Alaska Region.

Detailed stream flow information has been or is currently being collected at 75 locations in Alaska. Stream flow data are available for 21 gage sites on the Arctic and Yukon Flats national wildlife refuges. Kenai Refuge stream flow data for 15 sites will be published and available in the fall of 2002. Stream flow data are being collected and analyzed for an additional 39 gage sites located on the Becharof, Innoko, Togiak, and Kodiak refuges. Preliminary data for these stations is available on request.

Lake elevation surveys of selected lakes are conducted to determine lake water surface levels to support instream water right applications. Hydrologic investigations have been completed along the Coastal Plain (1002 Area) of the Arctic National Wildlife Refuge and on the Yukon Flats National Wildlife Refuge. Lake bathymetry data are available for 119 lakes and lake elevation data have been reported for 150 lakes on the Coastal Plain, and 63 lakes in the southern portion of the Yukon Flats National Wildlife Refuge.

The Water Resources Branch began a water quality program in the summer of 2001 to monitor water chemistry on the Togiak Refuge. Samples are collected at stream gage sites and analyzed several times each year. Data collection will expand to include the Kodiak Refuge in 2002.

Alaska Peninsula NWR
No stream gauging stations are being monitored in the Alaska Peninsula National Wildlife Refuge.

Becharof NWR
One stream gage at Egegik River is in operation at the outlet of Becharof Lake on the Becharof National Wildlife Refuge.

Kenai NWR
There were 15 stream discharge-gauging stations on the Kenai Wildlife Refuge.

Bureau of Land Management (BLM)
http://www.ak.blm.gov/ak930/hydro.html
BLM has extensive experience and expertise in hydrologic process studies such as the effects of water on soil, air and vegetation. BLM currently monitors stream flow on many large river systems on public lands in Alaska. This information is used, in part, to design channel reclamation for streams disturbed by placer mining. Other water resource projects include instream flow studies, water rights, aufeis, warm springs and snow surveys. BLM also manages units of the national wild and scenic rivers system and other federally administered rivers to protect resource and social values.

Environmental Protection Agency, Alaska Region
Many opportunities exist for partnering and sharing information with EPA in areas of wetland, water quality, and air quality monitoring. EPA has developed several national biological monitoring strategies to help ensure that chemical, physical and biological data is scientifically sound and geographically comparable. EPA has prepared "state-of-the-science" information that may prove help in

developing biological assessment methods to evaluate both the overall ecological condition of lakes and wetlands. Common themes exist between the NPS vital signs monitoring program and EPA's Environmental Monitoring and Assessment Program (EMAP). EMAP is designed to provide tools to monitor and assess the condition of the nation's freshwater and coastal systems.

National Weather Service
http://aprfc.arh.noaa.gov/
The National Weather Service provides on-line data about Alaska River Data Sites. There are few sites located near SWAN parks with minimal data. Site located near SWAN parks are:

- King Salmon Creek
- Newhalen River near Nondalton
- Tlikakila River near Port Alsworth
- Johnson River above lateral glacier near Tuxedni Bay
- Upper Nuka River near park boundary
- Resurrection River near Exit Glacier Bridge
- Resurrection River near Seward Highway Bridge

National Resource Conservation Service, Alaska Snow, Water & Climate Services
http://www.ak.nrcs.usda.gov/
NRCS collects and stores information on snow and ice surveys.

US Army, Corps. of Engineers, Alaska District
http://www.poa.usace.army.mil/en/cw/index.htm
The Civil Works Branch of the Alaska District studies potential water resource projects in Alaska. These studies, usually requested by a community in Alaska, analyze and solve water resource issues of concern to the local communities. These issues may involve navigational improvements, flood control or ecosystem restoration.

Besides studying water resource issues, the Civil Works Branch also track flood hazard data for over 300 Alaskan communities on floodplains or the sea coast. These data help local communities assess the risk of floods to their communities and prepare for potential future floods.

US Army, Cold Region Research and Environment Lab (CRREL)
http://www.crrel.usace.army.mil/
CRREL is a research and engineering facility located in Hanover, New Hampshire, with a project office at Fort Wainwright, Alaska. CRREL mission is to gain knowledge of cold regions through scientific and engineering research and put that knowledge to work. CRREL is the DoD's only laboratory that addresses the problems and opportunities unique to the world's cold regions. Of the several objectives of CRREL, the most closely related is the… "Conducting fundamental research to understand the nature and characteristics of snow, ice, frozen ground

and other materials in cold environments including their interrelationship with other environmental parameters."

US Geological Survey, Water Resources of Alaska (USGS)
http://www-water-ak.usgs.gov/
USGS is the lead agency in Alaska for the collecting and processing of hydrologic data and conducting basic and applied research in hydrologic topics unique to cold climates. SWAN goals for long-term monitoring overlap many of the goals of the USGS National Water-Quality Assessment (NAWQA) Program which are to (1) describe current water-quality conditions for freshwater streams and aquifers, (2) describe how water quality is changing over time, and (3) improve our understanding of the primary natural and human factors affecting water quality.

State Agencies

Alaska Department of Environmental Conservation (ADEC)
ADEC is the principal state agency charged with monitoring water and air quality. Water resource priorities include:

- Assess the effectiveness and gaps in Alaska's water stewardship programs- Stewardship uses our existing laws and practices to preserve and protect water quality, water quantity and aquatic habitat.
- Assess the health of Alaska's surface and ground waters- with public input, establish a ranked ACWA Waters List to prioritize needs for more knowledge about conditions or to take corrective action.
- Direct funding towards data collection or corrective action projects that protect restore or recover the valued uses of waters that are at risk or polluted.

Alaska Department of Fish and Game (ADF&G)
ADF&G is the primary state agency involved with surveys and monitoring of freshwater fish and sport and commercial harvest of fish. In the past, the Sport Fish Division has partnered with NPS in southwest Alaska for lake surveys, creel surveys, and fish population surveys. Most recently, biologists from Dillingham worked with Lake Clark and Katmai staff in developing thermal habitat model to predict sustainable harvest of lake trout.

Local Governments

Information regarding freshwater monitoring activities within the local governments was not readily available. Possible partners are:

- Lake and Peninsula Borough
- Kenai Peninsula Borough
- Bristol Bay Borough
- Bristol Bay Native Corporation
- Cook Inlet Regional Corporation

Universities

Alaska Cooperative Fish and Wildlife Research Unit- UAF
The Alaska Cooperative Fish and Wildlife Research Unit is part of a nation-wide cooperative program, initiated in 1935, to promote research and graduate student training in the ecology and management of fish, wildlife and their habitats. Located on the UAF campus and administered through the UAF Institute of Arctic Biology, the Alaska Unit is staffed by USGS-salaried scientists who hold regular faculty appointments and UAF-salaried personnel who provide administrative support. At present, the Alaska Unit sponsors 44 projects and 30 graduate students in research topically ranging from productivity of fish and wildlife populations to effects of contaminants on coastal ecosystems, and geographically from southeast Alaska rain forests to the tundra of southwest Alaska and the North Slope. The unit has a long history of conducting limnological and fisheries research in southwestern Alaska including most of the network parks.

University of Alaska, Fairbanks – Water and Environmental Resource Center (WERC)
http://www.uaf.edu/water/index.html
WERC's mission is to perform basic and applied research related to water and environmental resources, to train graduate students at master's and PhD levels in this field, and to disseminate pertinent research information to the public. Faculty, staff, and students at WERC are working to develop a better understanding of the arctic and subarctic environments. Research disciplines at WERC include environmental, civil, and mechanical engineering; oceanography; limnology; hydrology; microbiology; geochemistry; and hydraulics. WERC scientists are conducting cutting-edge research to help improve the quality of life for arctic inhabitants while supporting careful and sustainable development of Alaska's bountiful natural resources, protecting fragile ecosystems, and seeking to better understand the role of the arctic and subarctic in the global system.

Selected Current Research Projects:
- Hydrologic links with arctic freshwater and terrestrial systems
- The effect of climatic warming on arctic and subarctic ecosystems
- 3-D hydrological and thermal model for high-latitude watersheds
- Juvenile fish-passage design for stream crossings in Alaska
- Efficacy and toxicity testing of dispersants and dispersant-petroleum mixtures in the Alaskan marine environment
- Hydrologic processes in the Arctic (past project)

Other possible Universities:
- University of Washington, CESU
- Lake Illiamna Research Station

Committees and Consortiums

Interagency Hydrology Committee for Alaska
http://www-water-ak.usgs.gov/ihca/index.htm
The Interagency Hydrology Committee for Alaska (IHCA) is an organization of technical specialists working at the Federal, State, and local levels, who coordinate the collection and implementation of water resources related data throughout the State of Alaska. The IHCA meets twice per year to coordinate multi-agency issues and exchange of information.

Arctic System Science (ARCSS), Study of Environmental Arctic Change (SEARCH)
The Arctic Community-wide Hydrological Analysis and Monitoring Program (CHAMP) is a new initiative aimed at understanding the physical, biological, and biogeochemical controls on the components of the integrated arctic hydrologic cycle, and addressing linkages between the land and ocean. Key challenges in studying arctic hydrology include a sparse and declining observational network, lack of understanding of the basic hydrological processes operating across the pan-Arctic, and lack of cross-disciplinary synthesis. To address these challenges, members of the scientific community have recommended that the National Science Foundation invest in the development of a pan-Arctic hydrological analysis and monitoring program. The Arctic-CHAMP program will provide a framework for integrative studies of the pan-Arctic water cycle.

Other possible Committees and Consortiums:
- Exxon Valdez Oil Spill Trustee Council
- Cook Inlet Keepers
- Cook Inlet Information Management & Monitoring (CIIMMS)
- Trout Unlimited

Ecological Profile - Freshwater Ecosystems
Aniakchak National Monument and Preserve

Physical Environment

Aniakchak National Monument and Preserve (ANIA) is located 400 miles southwest of King Salmon on the Alaska Peninsula. During the Quaternary period, volcanoes in and near Aniakchak have been active, with the dominant volcanic center at Aniakchak Volcano. Ancestral Aniakchak Volcano underwent a catastrophic explosive eruption about 3400 years BC, blanketing much of the surrounding landscape with thick, fast-moving pyroclastic flows. Eruptions continued after the Aniakchak Caldera was formed. The Caldera is approximately 6 miles in diameter and encompasses an area of approximately 13.5 mi^2. The rim averages 3281 ft in elevation with the highest point reaching 4400 ft.

Post formation volcanic activity within the caldera has resulted in the emplacement of numerous lava domes, maars, eruption pits and lava flows (Miller, 1990). The most recent eruption occurred in 1931 from a side vent in the caldera floor. The caldera remains thermally active as evidenced by the presence of several warm springs as well as areas with ground temperatures of $185^oF(85^oC)$ at depths of 10 inches (Miller, 1990).

Freshwater Lakes

Aniakchak has three lakes within its boundaries. Surprise Lake, a large (660 acre) lake located along the northeast edge of the caldera floor, is a relict of an ancient lake. It drains 80% of the caldera and is fed by 11 surface inlets and numerous warm and cold springs (Cameron, 1992). A deep lake once filled much of the caldera (McGimsey et al., 1995). The lake eventually breached the caldera rim eroding a cleft in the eastern portion of the wall. This area is commonly referred to as "The Gates".

"Turbid Lake" is an unnamed maar lake, of grey-green color, formed by the drainage of a stream with a high load of suspended particles flowing into an eruption pit. It also resides inside the caldera. Outflow from the lake is underground for 100 feet before resurfacing, with suspended particles little reduced.

Meshik Lake is the only lake outside the caldera walls and is about half the size of Surprise Lake.

Freshwater Streams

Surprise Lake is fed by 11 surface inlets and springs. Several of the inlets are transporting large loads of ash into the lake and many of the inlet streams and springs are influenced by hydrothermal fluids.

Almost 100 feet wide and four to six feet deep the Aniakchak River surges from Surprise Lake and heads east toward "the Gates" where it exists from the caldera. "The Gates" are vertical walls of uniform horizontal strata of banded gray sedimentary rock while the east rim of the crater has been breached by part of a large rift. About 500 feet wide at the bottom and less than 2000 feet at the top, the sheer walls of "the Gates" tower more than 2000 feet above the river. In the upper 5 miles the river drops rather uniformly at a rate of about 100 feet per mile. The lower 17 miles flow through a broad valley up to 3 miles wide down to Aniakchak Bay. Despite its small volume and relatively short length compared to other Alaska rivers, the Aniakchak River is the largest river on the Alaska Peninsula draining into the Pacific Ocean.

Tributary streams of the Aniakchak River carry a high sediment load which is deposited as soon as velocities slow on less steep areas. Streams are highly meandered and braided.

Climate

Aniakchak's climate is cool, windy, and wet. Storms, brought by Pacific Ocean winds, frequently visit the area. The Aleutian Range acts as a weak physical barrier between two climatic zones: the Pacific Coast and Bristol Bay climatic regimes. The Pacific Coast has a maritime climate characterized by high precipitation and moderate temperatures. Bristol Bay has a more continental climate with lower precipitation, foggy summer days and wider temperature ranges. Weather inside the caldera is affected by shifting air currents that carry weather from the two climate zones as well as by its own topography. Low cloud ceilings, rain and high winds are common, even when the weather is relatively calm outside the caldera.

Although no rain gauges or other weather measurements are located in the monument, annual precipitation along the coast probably averages 100 inches or more. Precipitation on the Aleutian peaks and in the caldera is doubtless higher yet. Sunny days in the summertime are rare, and cloudy skies predominate in other seasons as well. The caldera has its own microclimate. Because of its topography and setting it appears to generate its own weather.

Biological Resources

With the exception of a few isolated cottonwood and willow trees that grow in the Cinder River drainage, the most prominent vegetation stands are the willow and alder shrubs that grow in thickets near Meshik Lake. Moist or wet tundra predominates to the north and west of the Aleutian Range. Alpine tundra is found east and south of the mountains. On the peaks and in the caldera, the vegetation is sparser than that found in lowland areas.

Freshwater systems in Aniakchak National Monument and Preserve are generally less diverse than in Katmai. Aniakchak has two lakes with anadromous salmon runs, though the lakes and their associated salmon runs are small relative to other area systems. Surprise Lake drains down the Aniakchak River to the North Pacific Ocean, while Meshik Lake drains down Meshik River to Bristol Bay near Port Heiden. Aniakchak has few pothole lakes, as most of the unit is in mountainous terrain. Wetlands are less extensive than in KATM as the soil throughout ANIA tends to be highly volcanic and porous, leading to faster drainage and fewer areas with standing water (and, mercifully enough, relatively few bloodsucking insects…). Documented freshwater fish diversity in Aniakchak is low, but a substantial intertidal zone in the Aniakchak River suggests that there is probably significant transient marine diversity in the unit as well.

The Meshik and Cinder River systems have large runs of all five species of salmon: king, chum, coho, pink and sockeye. Smaller streams have runs of sockeye and chum. Surprise Lake provides spawning habitat and a nursery environment for anadromous sockeye salmon and Arctic Char (Mahoney and Sonnevil, 1991). Dolly Varden, arctic char, and other species occur in most streams.

Macroinvertebrate collections made in inlet streams into Surprise Lake identified a number of non-insect taxa (Cameron and Larson, 1992). A previously undescribed species of Stygobromus was found in the gravel area near a cold springs (species account by Holsinger, 1997). The range of the species is unknown and to date found only in one inlet stream.

NPS Natural Resource Inventories and Monitoring

Fisheries surveys were conducted in Surprise Lake in 1987 by US Fish and Wildlife Service personnel during a 3 week trip to the caldera. A bathymetric map was prepared on that trip as well as some water quality analysis from lake and inlet stream waters (Mahoney and Sonnevil, 1987).

Cameron (and Larson, 1992) conducted a two year study of physical, chemical and biological attributes of Surprise Lake. His study was the first comprehensive baseline study in the lake. From his field work, Cameron concluded,

> Many of the inlet streams and springs are influenced by hydrothermal fluids. In the vicinity of inlet streams and springs influenced by hydrothermal fluids, the near lake surface increased in temperature, conductivity, trace elements, and periphyton biomass, and decreased in pH and dissolved oxygen. For the whole lake, water quality and trace element concentrations were influenced to a lesser degree by the hydrothermal inputs. Bright orange precipitates deposited in the lake at the

mouths of hydrothermal springs during winter were periodically suspended by easterly winds greater than 25 km/hr [15.5 mi/hr] between ice-out and late July, changing the lake color to olive green. The precipitates settled slowly during calm periods. The supply of precipitates for suspension diminished by the end of July. By mid-August, Secchi disk clarity increased to a summer maximum, and the color of the lake turned blue-green.

The phytoplankton community included 22 taxa dominated numerically by cyanobacteria. Chlorophyll was low in concentration. The maximum concentration of chlorophyll was associated with a decrease of Secchi disk clarity in late August.

The zooplankton community included three crustacean species and nine rotifer species. Polyarthra and Bosmina were the most abundant zooplankters, reaching their peak densities in mid-summer when Secchi disk clarity and chlorophyll concentrations were increasing. All other zooplankton taxa were at their highest densities in either early or late summer. The bottom fauna was dominated by oligochaetes near the mouths of the hydrothermally influenced streams and springs, while Stictochironomus and oligochaetes dominated littoral areas near cold springs. A mid-depth group was dominated by Sphaeriids and oligochaetes. Sphaeriids and chironomid pupae dominated the deep lake.

Human Activities With the Potential to Affect Freshwater Resources

1. **Commercial Fishing**. Harvesting of salmon, especially in the commercial fishery, may be one of the greatest threats to the Surprise Lake/Aniakchak River system. Overharvest may adversely effect salmon endemic to this system and alter the volume and distribution of nutrients in aquatic-terrestrial food web.

2. **Subsistence and Recreational Activities**. Camping and river float trips occur along riparian areas of the Aniakchak River and off-road vehicle (ORV) use occurs in wetlands and along stream channels on the coastal drainages. Erosion and compaction associated with these activities may have localized adverse effects on stream morphology and spawning habitat.

3. **Global Warming**. ANIA's environment is thought to be very susceptible to climate change. For example, Pinney and Begét (1991) reported that rapid environmental changes and glacial fluctuations on the Alaska Peninsula might be in response to transient changes in the concentration of atmospheric greenhouse gases and solar intensity. Climate also has a great influence on peatlands, which are found in

ANIA's lowlands (Belland and Vitt, 1995). Changes in moisture supply and thermal regime could alter topography and vegetation, which in turn could alter the water surfaces of northern peatlands and thus alter the natural delivery of CO_2 and CH_4 from surface waters to the atmosphere (Rouse et al., 1997). Increases in temperature can also extend ice-free seasons which will usually lead to increases in the ratio of evaporation + evapotranspiration to precipitation, resulting in less water found in the landscape (Schindler, 1997).

4. **Air quality.** While it is assumed that ANIA's air is pristine because of its remote location, this assumption cannot be validated due to the dearth of air quality data collected in the park. The global dispersion and deposition of pollutants has subjected many remote areas to pollutants, e.g., Barrow, Alaska. Additionally, problems associated with global warming, Arctic haze, ozone depletion, and acid precipitation extend beyond regional airshed boundaries to affect the entire planet.

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Ecological Profile - Freshwater Ecosystems
Katmai National Park and Preserve

Physical Environment

Katmai National Park and Preserve (KATM) lies astride the Aleutian Range on the Alaska Peninsula between the first and second largest lakes in Alaska: Iliamna and Becharof. This dynamic land has been repeatedly raked by massive glaciations, buried in volcanic ash, and beset by howling storms from the North Pacific. Its lakes and streams nurture, and are nurtured by some of the largest salmon runs in the world. Migrating waterfowl nest in the gentle marshlands, huge bears fatten up for hibernation on the spawning salmon, seals and whales patrol the coastal lagoons and offshore waters and vegetation struggles to recolonize a barren, wind blasted ash-covered land.

The geologic setting of KATM is astride a convergent plate margin. This setting has given rise to some of the most spectacular geologic features and events in recorded history. The Aleutian Range in KATM is a segment of the circum-pacific *Ring of Fire*, one of the most active volcanic belts in the world. Volcanic eruptions have occurred with some regularity on the Alaskan Peninsula. The most notable eruptions occurring in KATM in historic time are the 1912 eruption of Novarupta, which lead to the establishment of Katmai National Monument, followed by the 1952 eruption of Mt. Trident. Minor ash eruptions and outbursts have also occurred on Mount Mageik, Mount Martin, Novarupta and Mt. Katmai since the 1912 eruption (Wilcox 1959:419).

Basins

KATM is contained within five river basins (see map). The Naknek, Kvichak, and the Egegik River Basins are on the western side of the Aleutian Range and drain into Bristol Bay. The North and South Coastal Basins are on the eastern side of the Aleutian Range and drain into the Cook Inlet and the Shelikof Strait, respectively. Within these five watersheds are a great diversity of rivers and lakes.

The Naknek River Basin

The Naknek River Basin is the largest drainage basin in Katmai. Seventy-three percent (2,660 mi^2) of the 3,640 mi^2 drainage is located within Katmai's boundary (U.S. National Park Service 1997:26). The Naknek River flows approximately 35 miles from its outlet in Naknek Lake to Kvichak Bay and drains seven major lakes in the park: Naknek, Brooks, Coville, Grosvenor, Idavain, Murray, Hammersly. The Naknek River is a major producer of sockeye salmon with total runs averaging 5.0 million from 1983-1992 (Crawford and Cross, 1995). Fish are harvested by commercial fishers in a commercial gill net fishery in Bristol Bay, by sport and subsistence fishers in Naknek River, and by sport fishers in Katmai.

The Kvichak River Basin

The Kvichak River Basin is 60 miles wide and extends 170 miles in its greatest length diagonally from southwest to northeast. (U.S. Department of the Interior, 1952). This basin contains two large lakes located outside of the park's boundary: Lake Clark (143 mi^2) and Lake Iliamna (1,226 mi^2), the largest lake in Alaska. KATM occupies only a small portion of this larger watershed, which includes the Alagnak River, Kukaklek Lake, and Nonvianuk Lake.

The Alagnak River is one of the major tributaries in the Bristol Bay. The Alagnak River originates at Kukaklek Lake at an altitude of 800 feet and flows westward to the Kvichak River. It is 74 miles in length. The first 20 miles of the river are steepest, falling roughly 17.8 feet/mile. After the confluence of the Nonvianuk and Alagnak Rivers the remaining 54 miles are more gradually sloping, averaging 7.8 feet/mile (Clay, Inghram, and Carrick, 1983:3). The Nonvianuk River drains Nonvianuk Lake. It measures 11.5 miles in length from the lake to the confluence with the main stem of the Alagnak. The average gradiant is 15.2 feet/mile (Clay, Inghram, and Carrick, 1983:3). The largest streams located in the Alagnak River drainage in KATM are the Alagnak, Nonvianuk (or Branch), Kulik and Battle rivers and Nanuktuk, Moraine, and Funnel creeks.

The Egegik River Basin

The southwest corner of the park is contained within the Egegik River Basin. The Egegik River Basin extends from within 5 miles of the Shelikof Strait coast to Bristol Bay, and is approximately 40 miles in length (U.S. Department of the Interior, 1952). Contact, Angle and Takayoto creeks are the largest rivers within the park for this Basin. They flow west into the King Salmon River. The headwaters of the Kejulik River lie in the park's southeastern end. The river drains into Becharof Lake in the Becharof National Wildlife Refuge.

The North Coastal Basin

The North Coastal Basin drains into Cook Inlet. Along Katmai's coast, the Kamishak River, Little Kamishak River, Strike Creek, and Douglas River flow into Kamishak Bay located in Cook Inlet.

The South Coastal Basin

The South Coastal Basin drains into Shelikof Strait. Numerous named (e.g., Katmai River, Alagogshak Creek) and unnamed streams flow down the characteristically short, steep drainage into the Shelikof Strait (U.S. National Park Service, 1994). A number of the coastal streams flow from massive glaciers of the Aleutian Range. The lake at the base of Hallo Glacier is only 150 feet above sea level. Several streams, such as the Katmai River, are heavily laden with volcanic ash. This heavily braided river is almost 3 miles wide. Its channels run through soft ash laden mud terminating at the sea where a mixture of ash and pumice sit 2 to 5 feet deep.

Freshwater Lakes

KATM contains the largest freshwater lake in the National Park system (Naknek Lake) and some of the largest lakes in Alaska (Table 1). These lakes make up approximately 8% of the park's surface area and most are found at low elevations (< 1000 feet msl) along the northern slope of the Aleutian Range. These lakes range from 10 to 518 meters in altitude and from 1 to 228 mi^2 in area. Maximum depths in the lakes that have been mapped range from 21 to 173 meters (Burgner et al., 1969:409).

The Naknek River Basin

Coville, Grosvenor and Naknek lakes form a chain of lakes that drain into the Naknek River. Starting at the headwaters, Coville Lake has the shallowest basin receiving its water from snowmelt and runoff via the 80 km American Creek. It serves as a settling basin for downstream Grosvenor Lake. Grosvernor Lake drains into Savonoski River. Savonoski River also receives drainage from glacier fields, then flows into Iliuk Arm of Naknek Lake. In addition to the glacial runnoff from Savonoski River, Iliuk Arm receives ash flows from the Valley of Ten Thousand Smokes via the Ukak River. Heavy loads of rock flour and ash from these sources significantly effect water quality and transparency at the east end of the lake. Westward the clear Brooks Lake flows via the Brooks River into the Naknek mixing with the turbid waters of Iliuk Arm. Brooks Lake receives runoff from low mountains and lowland wet tundra and from snowmelt. Snowmelt and runoff from wet tundra supply water to the North Arm of Naknek Lake. The west end of the lake is relatively shallow and separated from the North Arm by a moraine.

Table 1. Major Lakes Contained within the Naknek River Drainage of Katmai (U.S. National Park Service, 1994 and Burgner et al 1969:409).

Lake Name	Area (mi^2)	Maximum Depth (m)	Altitude (feet)	Lake Name	Area (mi^2)	Maximum Depth (m)
Naknek	228	564	33	Idavain	4.2	69
Brooks	29	258	62	Hammersly	3.4	No data
Grosvenor	29	349	101	Jo-Jo	2.6	No data
Coville	13	173	108	Murray	1.0	No data

The Kvichak River Basin

The Alagnak River is a “Wild River” component of the National Wild and Scenic Rivers system and a unit of the NPS administered by KATM staff. The Alagnak River is a tributary of the Kvichak River Basin. Major lakes contained in the Alagnak drainage are presented in Table 2. Lakes in the drainage lie between 192 and 254 meters and vary in size from 13 to 177 km^2.

Table 2. Major Lakes Contained within the Alagnak River Drainage of Katmai National Park and Preserve (U.S. National Park Service, 1994 and Burgner et al 1969:409).

Lake Name	Area (mi^2)	Altitude (feet)	Lake Name	Area (mi^2)
Kukaklek	67.5	802	Pirate	0.8
Nonvianuk	51.5	626	Spectacle	0.8
Kulik	10.7		Mirror	0.6
Battle	5.0		Iron Springs	0.3

The Egegik River Basin
There are no large lakes in the Egegik River Basin.

The Coastal River Basins
There are fewer lakes located along the Shelikof Strait coast. These coastal lakes are much smaller than those found in the interior of the park. Heard et al. (1969) believes that most lakes along Katmai’s coast are glacial in origin and are relatively deep for their size. Dakavak Lake is the largest coastal lake, approximately 2.8 miles long and 0.6 miles wide (1.7 mi^2) with a depth greater than 69 feet.

Freshwater Streams

Katmai has an extensive and diverse array of stream types, from steep, glacial fed rivers to small, intermittent streams varying in gradient, rate of flow, and geology. Streams draining the eastern side of the Aleutian Range are typically short, high gradient on bedrock. In contrast, on the western side of the range rivers flowing toward Bristol Bay consist of large, low gradient rivers and small, low gradient stream complexes. Generally anadromous fish uses only low gradient streams.

The Naknek, Savonoski, American, Alagnak, Margot, Nonvianuk and Brooks Rivers are among the largest in the park west of the Range. Of the coastal rivers, the Douglas, Big, Kamishak and Katmai are a few of the largest. Large rivers in the park receive clear water tributaries but are frequently dominated by glacial runoff and carry large silt loads. They take on the characteristics of their upstream tributaries and generally show a great deal of similarity along their course. These rivers are resistant to small scale perturbations due to their size and the volume of water flowing through the system. Large rivers act as corridors for fish to migrate to clearwater streams and side channels and sloughs provide important rearing habitat for salmonids.

Streams in the Valley of Ten Thousand Smokes vary considerably from the general description of river systems outside the 1912 ash flow. Weathering of the 1912 ashflow, input from thermal and cold springs result in very different physical and chemical properties of these waters. Fish do not spawn up these streams and very few wildlife observations are made in the mostly barren ash flow. Vegetation plays little role in the cycling of nutrients. Knife Creek and River Lethe, the two major streams draining the deposit; are enriched in dissolved constituents (SiO_2, Ca, Na, K, Mg, Li, Cl, Fe, SO_4) compared to streams and springs that have not had contact with the ashflow (Keith et al., 1990:1691). They also have greater concentrations of these constituents the longer they flow through the ash, meaning that lower reaches of the rivers have higher concentrations than those 20 km up valley (Keith et al., 1992). Downstream increases in dissolved constituents are thought to be in part caused by the entry of thermal waters mid-valley and in part by dissolution of unstable or metastable fumarolic minerals.

Wetlands

KATM contains extensive wetlands that include marine, estuarine, riverine, palustrine, and lacustrine environments (estimates exceed 1 million acres). The park's wetlands represent transitional environments, located between uplands and deepwater areas. Flora within these wetland systems exhibits extreme spatial variability, triggered by very slight changes in elevation. Temporal variability is also great because the surface water depth is highly influenced by changes in precipitation, evaporation and/or infiltration.

There are a number of tundra ponds, beaver ponds, and small tundra lakes along the park's western and northern boundary. These bodies of water are shallow, frequently contain submerged and emergent aquatic vegetation, and occasionally have no surface connections with major stream systems (Heard et al., 1969). The Savonoski River/Bay of Islands area and the Margot Creek drainage, located in the park's interior, also contain extensive marshes and ponds.

Glaciers, Lake Ice, and Snowpack

Glaciers make up 216,000 acres (6%) of KATM(U.S. National Park Service, 1994). The hydrologic cycle in the park is influenced in part by extensive glaciers and snowfields that supply vast quantities of silty meltwater to the headwaters of drainage basins during the summer months.

Lakes at lower elevations in the Naknek drainage usually freeze by early December and become ice free in early May (Heard et al., 1969 in Buck 66). Higher elevation lakes, such as Murray and Hammersly, may remain under ice for several weeks longer. In fact, local reports indicate solid lake ice as late as June (Sonny Petersen, personal communication, July 2001). The lower Naknek River is generally open between mid-March and late April with an average break up date of April 9 (US Dept of Commerce, 1964).

Naknek Lake freezes earlier in winter than Lake Iliamna because it is more sheltered from prevailing winds (Hartman et al., 1967). However, Goldman (1960), Merrell (1958) and others report open water on Iliuk Arm in mid-winter when air temperatures are below 0^{o}C. Early explorers witnessed this phenomena and attributed it to the presence of hot springs in the area. Later scientists attribute the open ice conditions to Iliuk Arm's depth (Goldman, 1960:225).

Climate

KATM's eastern and southern coasts bordering Shelikof Strait have a Maritime climate characterized by small temperature variations, high humidity, heavy precipitation, high occurrence of clouds and fog, temperatures generally above freezing, cool summers, and warm winters. Maximum summer temperatures are generally in the 50 ^{o}'s F (10^{o} C -15^{o} C) and winter lows are in the 20^{o}'s F (-7^{o} C –1^{o} C) (Selkregg, 1976). The Aleutian Range runs along KATM Shelikof coast leading to precipitation that ranges between 20 inches (50 cm) and 70 inches (180 cm)(Jones and Fahl, 1994). Precipitation on the high eastern flank of the Aleutian Range may exceed 200 inches (500 cm) per year. Surface winds are strong and persist throughout the year.

The majority of KATM's climate can be classified as Transitional with conditions intermediate between Maritime and Continental. Climatic conditions for the Maritime region of KATM are better characterized using data from the NWS station on Kodiak Island. Additionally, local geographic conditions produce a variety of microclimates that are impossible to delineate due the lack of spatial and temporal historical weather data.

The mean annual temperature at King Salmon ranges between 15.4^{o} F (-9.2^{o} C) in January to 55.7^{o} F (13.2^{o} C) in July. Temperatures on Kodiak Island, which are more representative of Katmai's Maritime climate, range between 29.7^{o} F (-1.3^{o} C) in January and 5.0^{o} F (12.8^{o} C) in August. (Figure 2, Western Region Climate Center Data, 2002). The mean monthly temperatures for Kodiak and King Salmon are 40.5^{o} F (4.7^{o} C) and 34.5^{o} F (1.4^{o} C), respectively.

Precipitation for the Kodiak Island station ranges between 4.12 inches (10.5 cm) in July and 8.36 inches (21.2 cm) in October with an annual precipitation 75.35 inches (191.4 cm).

Southeasterly and easterly winter winds predominate in the King Salmon area for the months from October to March (Waythomas, 1994). Winter winds are associated with high pressure over northern Alaska and low pressure over the southern Bering Sea and Gulf of Alaska. Summer winds, present between June and September, are generally from the south or southeasterly direction. During the late winter and early spring, February to May, winds are from the north or northeast. Strongest winds for King Salmon come from the east. Average wind speeds for King Salmon display little monthly variability with a high of 11.5 mph (18.6 km/hr) in March and a low of 9.9 mph (16 km/hr) in July (NOAA, 1998). Winds for Kodiak display greater seasonal variability with high winds in winter and lower winds in summer. The highest winter monthly average wind speeds is12.7 mph (20.6 km/hr) found in both December and January, while the lowest monthly average is 7.7 mph (12.5 km/hr) in July (NOAA, 1998).

The climate of the Alaska Peninsula and KATM is heavily influenced by storms originating in the North Pacific and moving into the area along a storm track that parallels the Aleutian chain. Storm frequency for the KATM area is greatest during the late summer and early fall from August through October (Klein, 1957).

Biological Resources

The drainages within KATM support one of the largest sockeye salmon fisheries in the world. Sport fishermen from around the world spend thousands of dollars to stay at local lodges using fishing guides to locate the best fishing holes in KATM. Salmon, rainbow trout, arctic char and other fish are the focus of their efforts. The local as well as state economies are largely dependent on fish.

The most widespread and abundant fish species in KATM include Pacific salmon, trout, char, whitefish, and grayling (Table 5). Species of anadromous Pacific salmon in KATM include sockeye (red), chinook (king), coho (silver), chum (dog), and pink (humpy) salmon. Rainbow trout is the only species of trout known to occur in the park. Species of char include *lake* trout, arctic char, and dolly varden. Whitefish that are present include round whitefish, pygmy whitefish, broad whitefish, humpback whitefish, and least cisco. Arctic grayling is also present in the park.

KATM is unique in that it contains two populations of landlocked, freshwater sockeye salmon called kokanee salmon. Kokanee are rare in Alaska (Burger, 1991). These salmon are fully adapted to freshwater and therefore, reside in streams and lakes without migrating to the sea. They live in water accessible or inaccessible to anadromous sockeye. In KATM, the kokanee populations are known to occur in Kaguyak Crater Lake and Dakavak Lake (NPS 1999). However, Heard (1969) also reported that he collected Kokanee salmon from a small unnamed lake above the Devils Cove portion of Kukak Bay and Greenbank (1954:7) reported finding Kokanee in Jo-Jo

Lake. What is important about these fish is that in recent geologic time, Kokanee salmon populations have evolved from anadromous runs separately all over the world and biologists do not understand how or why these multiple, similar evolutions occur.

Table 5. Freshwater fish of Katmai National Park and Preserve
Source: NPSpecies

	Freshwater/Anadromous	
LAMPREYS	ARCTIC LAMPREY	*Lampetra japonica*
	AMERICAN BROOK LAMPREY	*Lampreta lamotteii*
WHITEFISHES	HUMPBACK WHITEFISH	*Coregonus clupeaformis (should be C. pidschian)*
WHITEFISHES	Lake Whitefish (may not be actual common name)	*Coregonus clupeaformis*
WHITEFISHES	LEAST CISCO	*Coregonus sardinella*
WHITEFISHES	PYGMY WHITEFISH	*Prosopium coulteri*
WHITEFISHES	ROUND WHITEFISH	*Prosopium cylindraceum*
TROUTS & SALMON	KAKONEE SALMON	??
TROUTS & SALMON	PINK SALMON	*Oncorhynchus gorbuscha*
TROUTS & SALMON	CHUM SALMON	*Oncorhynchus keta*
TROUTS & SALMON	COHO/SILVER SALMON	*Oncorhynchus kisutch*
TROUTS & SALMON	RAINBOW TROUT	*Oncorhynchus mykiss*
TROUTS & SALMON	STEELHEAD TROUT	
TROUTS & SALMON	SOCKEYE/RED SALMON	*Oncorhynchus nerka*
TROUTS & SALMON	CHINOOK/KING SALMON	*Oncorhynchus tshawytscha*
TROUTS & SALMON	ARCTIC CHAR	*Salvelinus alpinus*
TROUTS & SALMON	DOLLY VARDEN	*Salvelinus malma*
TROUTS & SALMON	LAKE TROUT	*Salvelinus namaycush*
GRAYLING	ARCTIC GRAYLING	*Thymallus arcticus*
SMELTS	POND SMELT	*Hypomesus olidus*
SMELTS	RAINBOW SMELT	*Osmerus mordax*
BLACKFISH	ALASKA BLACKFISH	*Dallia pectoralis*
PIKES	NORTHERN PIKE	*Esox lucius*
SUCKERS	LONGNOSE SUCKER	*Catostomus catostomus*
CODFISHES	BURBOT	*Lota lota*
STICKLEBACKS	THREESPINE STICKLEBACK	*Gasterosteus aculeatus*
STICKLEBACKS	NINESPINE STICKLEBACK	*Pungitius pungitius*
SCULPINS	COASTRANGE SCULPIN	*Cottus aleuticus*
SCULPINS	SLIMY SCULPIN	*Cottus cognatus*

Rainbow trout is another very important species of fish in KATM. While rainbows are not harvested commercially and are minimally harvested by subsistence fishermen, they support a world class sport fishery and attract anglers from all over the world especially to the Alagnak River. All access to the Alagnak River is by air, and this area is considered to be one of the most popular fly-in destinations in Southwest Alaska

(USGS, 1999). Little is known, however, about the ecology and life history of rainbow trout populations, along with most other species of fish in the Alagnak drainage.

Lake trout are the largest resident freshwater fish. Some of the largest probably exceed 50 pounds (ADF&G, 1994d). Arctic char and Dolly Varden char also occur in KATM. Arctic char are thought to be freshwater residents, although there is some evidence which indicates that there may be sea-going populations. Dolly Varden may occur as either freshwater or anadromous forms.

Round and pygmy whitefish are very common throughout the Naknek drainage in the main stem, lakes, and streams. The greatest density of round whitefish occurs in Coville Lake. Humpback whitefish are also present throughout the Naknek drainage and are concentrated heavily in the principal lakes, particularly Coville Lake.

The park is home to the largest protected population of brown bears in North America and prime spawning habitat for salmon, which is the foundation of the Bristol Bay commercial fishing industry – the largest in the world. During 1972-91, the annual run of sockeye salmon bound for the Naknek and Kvichak drainages averaged 15.3 million fish, 53% of the total Bristol Bay run. From 1985-91, the sockeye escapement into the Naknek drainage averaged 1.8 million, and 5.4 million into the Kvichak drainage (U.S. National Park Service, 1994). Harvests of wild salmon have declined in the past 5 years for a variety of reasons. But the largest factor affecting commercial harvests today is the competition from the sale of hatchery reared fish favored for their lower price at the market.

Diverse floral communities also exist in the park, in part because of the dynamic landscapes (i.e., glaciers, coast, lakes, rivers, etc.) and variation in topography, from sea level to 7600 ft. msl (U.S. National Park Service, 1994). Buck et al. (1978) prepared a comprehensive summary of natural resource information on the Naknek River drainage. This report includes an annotated bibliography and summary of the aquatic environments and biota, especially fisheries.

NPS Natural Resource Inventories and Monitoring

During the summers from 1990-1992, a study was conducted to begin establishing water quality baseline information at KATM (LaPerriere, 1996). This water quality study assessed conditions in 11 large lakes and some of the important inlet, outlet, and connecting streams along the Naknek and Alagnak drainages within KATM. Data needs and long-term monitoring recommendations for KATM were presented by LaPerriere (1996) and included:

1. Bathymetrically map large lakes as needed to compliment future studies.
2. Establish GPS-fixed stations in the deepest spot of major basins of each lake to be monitored. These sites will provide comprehensive (max. depth) water quality and biological profiles for each lake.
3. Take monthly Secchi disc readings during the ice-free season and calculate seasonal averages. Data will provide "early detection" of possible eutrophication and justification for intensive limnological studies.
4. Gage the largest streams in KATM in conjunction with the U.S. Geological Survey. Flow data are needed for any stream where water quality characteristics are being measured.
5. Monitor streams used for drinking water by staff and visitors for comparison to drinking water standards.

To follow-up with LaPerriere's study, KATM currently collects some basic water quality parameters (pH, turbidity, temperature, dissolved oxygen, Secchi depth readings, etc.) during the ice-free season for 11 lakes in the park (Hamon, pers. comm., 1999).

In 1996 and 1997, the U.S. Fish and Wildlife Service sampled six sites (three per year) for hydrocarbons in KATM waters that receive heavy public use (Kulik Lodge, Grosvenor Lake Lodge, Alagnak Wild River, Naknek Lake, Brooks Lake and Lake Camp). The elevated hydrocarbon concentrations and visual observations reported at several sites during this project justify the need for follow-up sampling and analyses (Johnson and Berg, 1999).

As a result of low alkalinity recorded in waters in the Alagnak drainage, Gunther (1992) stated that this drainage should be a high-priority for study if acidic deposition were to occur in the region. These studies would need to examine soil development and base-cation exchange capacity, the relative importance of surface and groundwater inflow in each drainage, and internal alkalinity generation in the lakes. It should be noted that the average pH recorded from 16 precipitation events in KATM (1985-1986) was 5.0, which is slightly acidic. Heavy metals were also found in the precipitation samples (U.S. National Park Service, 1994).

Basic biological knowledge of KATM's aquatic environments is also lacking. Buck et al. (1978) stated that research in the Naknek basin should focus on:

1) phytoplankton species distribution, abundance and diversity, and annual cycles of primary productivity;
2) zooplankton population dynamics;
3) invertebrate species distribution, abundance, and diversity, particularly aquatic insects;
4) salmon spawning areas, age structure, and juvenile use of habitats for coho (*O. kisutch*) and chinook (*O. tshawytscha*); and
5) population dynamics of rainbow trout (*O. mykiss*), lake trout (*Salvelinus namaycush*), Arctic grayling (*Thymallus arcticus*), Dolly Varden char (*S. malma*), and Arctic char (*S. alpinus*).

In response to the 1990 Aquatic Resources Inventory and Monitoring Workshop, Potts et al. (1993) prepared a proposal for long-term ecological monitoring for KATM. The objectives of this proposal were to establish KATM as one of the national Inventory and Monitoring prototype NPS units and to develop and implement a program of long-term ecological monitoring of the large lakes and large rivers in KATM. Unfortunately, this proposal was not funded at the national level (Deschu, pers. comm., 1999).

Flow Regimes

There are no continuous stream flow data in KATM. The closest USGS stream gaging stations are located outside the park at Eskimo Creek (Naknek River basin - King Salmon, AK) and Kvichak River (Kvichak River basin - Igiugig, AK). Between 1990 and 1992, discharge was recorded on 19 streams in the park. The reported discharges ranged from 2 ft^3/sec in a tributary that feeds Brooks Lake to 530 ft^3/sec in American Creek (LaPerriere, 1996).

Scattered discharge records exist for various drainages. Eicher (1971), Hartman (1958:148) and Hartman et al (1964) report a range of 250 – 603 cf/s for the Brooks River. Brooks Lake tributaries are reported to flow from 0.2 to 24 cf/s during the summer (Hartman 1958:149, Hartman 1959:72, Hoopes 1976 or 1972??). Individual measurements by Hartman et al (1962) report a range of 10 – 20 cfs for Hidden Creek and 15.7 for One Shot Creek, both tributaries to Brooks Lake. McAfee (1960) recorded water velocity for Brooks River and Up-a-Tree Creek at sites where sockeye spawn.

Summer discharge rates for Knife Creek are well over $7x10^5$ L/min and $5x10^5$ L/min for River Lethe near Three Forks. Mid-winter discharges are unknown (Keith et al., 1992:213). Windy Creek measured discharge in June 1991 was $2.84x10^5$ L/min. Flow is generally higher in early summer because of snowmelt at the headwaters and flow rate may double at any time during heavy rain in the headwaters region (Keith et al., 1992:214).

Human Activities With the Potential to Affect Freshwater Resources

1. **Discharge of water pollutants-** The primary and time-sensitive water resource issue at Brooks Camp is petroleum contamination of soils and ground water that resulted from a leaking NPS fuel distribution system. According to a U.S. National Park Service report (1997), this system, constructed in 1975, included two 8,000-gallon diesel underground storage tanks (USTs) that were connected by underground fiberglass piping to a 2000-gallon UST, a 500-gallon UST and numerous 62-gallon ASTs located at individual cabins. The 8,000-gallon tanks were filled from a fuel barge through an underground line that connected to a diesel fill box on the shore of Naknek Lake. At the southern portion of Brooks Camp, three 2,000-gallon USTs were used for bulk storage and to refuel vehicles. One 2000-gallon gasoline UST was located near the barge landing (immediately east of the Brooks River). Two other USTs, one gasoline and one diesel, were located in the vehicle parking area. In 1992, all USTs and underground piping failed to meet the Environmental Protection Agency (EPA) tightness test standards.

   Ground water at Brooks Camp occurs between 3 and 15 feet below ground surface in an unconfined aquifer. A site characterization performed in 1992 confirmed soils and ground water contamination from gasoline and diesel fuels and delineated a series of contamination plumes (Ecology and Environment, Inc., 1992). As a result, the leaking fuel distribution system was removed and a new system installed in 1993. Remediation of groundwater at Brooks Camp began in September 1998. Remediation will include limited soil excavation and on-site soil/ground water treatment (Ecology and Environment, Inc., 1993).

   Two shallow ground water wells that provided potable water for Brooks Camp were impacted by the petroleum contamination. As a result, two new replacement wells were installed into the deeper bedrock aquifer (62 ft. depth at Brooks Camp and 110 ft. depth at Brooks Lake). Bill Heubner (pers. comm., 1998) stated that this deeper saturated unit was observed to be under pressure during the drilling operations. This suggests a confining layer exists under Brooks Camp, which would help minimize vertical migration of petroleum contamination into the deeper aquifer. A clay-sand soil type that is reported to underlie the entire site is probably the confining unit that separates the shallow water table aquifer from the bedrock aquifer (U.S. National Park Service, 1997).

2. **Erosion and streambed alteration from boats**. Park visitation has risen sharply in the last decade. Sightseers, anglers, and hunters routinely fly or boat into KATM to take advantage of the park’s pristine natural resources. With an increase in visitor use comes an increase in resource impacts. For example, the recreational demands by freshwater anglers in southwestern Alaska have more than doubled over the past decade. As angling pressure increases in KATM, boat operators venture further into headwater streams to avoid crowding. Today, jet-driven boats are becoming more

popular because of their shallow draft. Shallow headwaters are preferred by Pacific salmon (*Oncorhynchus*) and rainbow trout (*Salmo gairdneri*) as sites of egg deposition for reproduction.

A study by NPS staff was carried out during the summers of 1986 and 1987 to evaluate resource condition under the current permit system. The most serious consequence of human activity along American Creek identified during the study was the increased rate of erosion and alteration of streambed morphology that results from jet boat use. Permanent photo points were established in 1989 to monitor riparian vegetation cover and erosion along the creek every 2 to 4 years, but they have since been discontinued (U.S. National Park Service, 1994).

Based on a 1992-1993 study by the University of Alaska at Fairbanks on American Creek, jet boat operation can lead to:

- significant salmonid embryo mortality through mechanical shock,
- intrusion of fine sediments into the gravel affecting eggs that remain in redds, and
- the removal of gravel covering eggs in redds with subsequent washing away of eggs (Horton, 1994).

Since 1983, recreational use on the Alagnak River has increased, and so have the water resource impacts. Although the river's riparian areas are generally undeveloped and heavily vegetated, the banks are actively eroding in several areas as a result of boat wake impacts. In 1998, the U.S. Geological Survey initiated an erosion monitoring effort on the Alagnak River (Dorava, 1998a). After monitoring 14 sites from July to September 1998, bank erosion measurements ranged from 0 to > 28 inches, where erosion exceeded the length of the erosion pin (Dorava, 1998b). Following this study an effort was initiated by the U.S. Geological Survey as part of a 3-year NPS/USGS water quality and monitoring partnership program, "Human Impacts on Water Quality and Riparian Habitats along the Alagnak Wild and Scenic River, Katmai National Park and Preserve" . The program includes a more comprehensive study of erosion and its effects on water quality. The final report on that project should be released in about November 2002.

3. **Commercial developments**. Seven backcountry lodges exist within KATM, and at least four more are being developed or planned on private inholdings, including the Alagnak Wild River, Naknek River and along the coast (Johnson and Berg, 1999). Although there is considerable information on a few popular facilities (i.e., Brooks Camp, Lake Camp), water resource impacts from most backcountry facilities and sites (i.e., concentrated camping areas) are not well documented. The U.S. National Park Service (1994) identified several on-going activities that could affect natural resources in Katmai's backcountry, including:

- Landing and beaching of floatplanes on lake shores and river banks;
- Landing of wheeled planes on beaches and gravel bars;
- Beaching of boats and rafts along river banks;
- Concentrated camping sites associated with water access (i.e., along river or lake banks);
- Use of all-terrain vehicles (ATVs) and four-wheel drive vehicles within KATM boundaries.

Katmai's staff conducted a Level 1 hazardous waste survey at the Grosvenor concessions area (Grosvenor Lake Lodge) in 1993. The lodge is located on the northeast side of a narrow neck of land that separates Lake Coville and Grosvenor Lake. At this particular facility there is a lodge, three cabins, bathhouse, kitchen, dining area, employee facilities, generator shed and maintenance shed. During the survey, areas adjacent to the generator shed were void of vegetation. The floor of the generator shed appeared to be contaminated from petroleum spills (McClenahan, 1993). In 1996, a hydrocarbon sampling effort at the lodge by the U.S. Fish and Wildlife Service revealed low levels of polycyclic aromatic hydrocarbons (PAHs), but visual observations of an oil sheen suggested a history of hydrocarbon contamination that might warrant further investigation (Johnson and Berg, 1999).

In 1996, the NPS contracted with the U.S. Fish and Wildlife Service to collect water and sediment samples at Kulik River Lodge for hydrocarbon analyses. According to the laboratory results, total PAH's did not indicate significant contamination at the site, but a hydrocarbon release in the past is a possibility (Johnson and Berg, 1999). The U.S. Air Force established two recreation areas immediately east of King Salmon in the 1950's. One site is located approximately 4 miles southeast of King Salmon and approximately 3.5 miles west of Katmai's boundary on the Naknek River. The other site is 6 miles east of King Salmon inside the park's boundary, along the banks of Naknek Lake. The Naknek River and Naknek Lake sites were used by the Air Force between 1956 – 1977 and 1956 – 1979, respectively. Along with these two sites being used as recreational areas, they were also used by the Air Force as landfills for hazardous materials. Waste oils, fuels, and polychlorinated biphenyl's (PCBs) were among the wastes disposed at these sites. A 1989 report prepared by the Hazardous Material Technical Center for Elemdorf Air Force Base concluded that a potential exists at both sites for contamination of surface water, soils, and/or groundwater. The Naknek River was listed by the Alaska Department of Environmental Conservation (1996b) as a high-priority water quality limited waterbody, which require water quality assessments to define the extent of pollution and what remedial efforts need to be employed. The pollutant sources were identified as "landfill" and "fuel storage". In 1997, sediment and water samples collected at the Naknek Lake site contained elevated concentrations of hydrocarbons (Johnson and Berg, 1999).

4. **Commercial, Sport, and Subsistence Fish Harvest.** Humans intercept and harvest many returning salmon and other fish in commercial, subsistence, and recreational fisheries. Harvesting of salmon, especially in the commercial fishery, represents the greatest threat to their populations, populations of other wildlife, and their natal ecosystems, which depend on them for food and the cycling of nutrients. KATM contains a substantial portion of sockeye salmon spawning habitat upon which the Bristol Bay commercial salmon fishery, and thus the regional economy depend. The U.S. National Park Service (1994) reports the most significant factor affecting salmon populations in KATM is the commercial fishery.

   There are numerous and complex sport fishery issues at Katmai. For example, there is escalating sport fishing pressure on the Alagnak River drainage with associated mortality and mutilation of rainbow trout, even though “catch-and-release” regulations are in effect. In response to fishery issues such as this, KATM has initiated the process to prepare a Fisheries Management Plan (FMP). Katmai’s FMP will be a comprehensive plan that prioritizes the park’s information needs for fisheries to address high-priority fishery issues. This plan will integrate NPS and State policies and appropriate legislative mandates into park-specific management actions. Some key sport fishery issues include:

   - Present and future growth of fishing activity;
   - Lack of information on stock status and health;
   - Crowding, fishermen experience, and loss of wilderness values;
   - Fishermen- wildlife interactions (particularly bear concerns);
   - Associated resource impacts including vegetation & water quality;
   - Safety concerns, and;
   - Jurisdictional overlap and need to coordinate fisheries management efforts.

5. **Air pollutants**. KATM is designated as a Class II floor attainment area for air quality protection. This designation allows for moderate increases in some pollutants, but PSD (prevention of significant deterioration) requirements remain in effect. Maintaining air quality is critical to preserve the park’s scenic value, as well as its wildlife and water quality. The Resource Management Plan for Katmai National Park identified several threats to air quality in the park (National Park Service, 1994:150). These included:

   - automobile and air traffic from King Salmon and Naknek

- smoke from incinerators, dumps, fireplaces, wood-burning stoves, and furnaces in the local area
- power generation from King Salmon, Naknek and local communities
- regional pollution from Dillingham and Kodiak
- campfires at Brooks Camp and backcountry site
- long distance transport from industrial areas

Several high altitude lakes in KATM have low alkalinity and are acid sensitive (LaPerriere, 1996). Naturally, acidic lakes are often located in volcanic areas and high aluminum concentration has been reported for several creeks in KATM (Gunther 1992, LaPerriere 1996). Areas with low alkalinity may be particularly sensitive to acid precipitation. The average pH for 16 precipitation events measured in 1985 and 1986 was 5.0. Although this pH is more acidic than pure rainfall in equilibrium with CO_2 (pH = 5.6), it corresponds to the value given for remote areas uncontaminated by industrial emissions or calcareous dust (Schindler, 1988:149). The pH values found for fresh snow and snowmelt on the Kenai Peninsula in 1981 was 5.2 (Alaska Department of Environmental Conservation, 1981).

Community Impacts- One potential threat to air quality in KATM is power generation from surrounding communities. Several areas were identified as potential contributors of pollutants to Katmai's airshed. These include King Salmon, Naknek, Dillingham, Illiamna, and Kodiak. The Naknek Electric Association operates a plant along the Naknek River approximate six miles (10 km) west of the park boundary. The Nushagak Electric Cooperative supplies power for Dillingham located 75 miles (125 km) west of the park. Kodiak has two generating stations: the Nyman Power Plant and the Kodiak generating station. The latter is used as an emergency back up and is not in regular use. Power for Illiamna is supplied by a hydroelectric generation station and back-up power comes from a generation station in Newhalen.

Arctic Haze and Visibility- A distinct haze was occasionally noted during monitoring in 1986 by KATM staff. Arctic haze was first observed over Alaska and reported upon during the mid-1950s in connection with weather reconnaissance flights over the state. Approximately 90% of Arctic haze is attributed to sulfate particles. Air masses associated with Arctic haze may transport pollutants for as long as a month before final deposition occurs. Studies on sources of Arctic haze have demonstrated that most of the haze in Alaska originates in northern central Russia and western Europe (Rahn and Lowenthal, 1986; Ratz, 1991). In contrast to Arctic haze, local and regional haze may be generated in close proximity to where it is observed. Local nitrous oxide emissions may be responsible for haze conditions. Given the relatively large emissions of NO_x from power generation, local emissions coupled with the right meteorological and atmospheric conditions (stable atmospheric inversions) may lead to haze in KATM.

Greenhouse Gases- Greenhouse gas impacts on Katmai's resources are based on an assessment of how the climate may be impacted by rising global concentrations of CO_2 and CH_4. Katmai's environment is thought to be very susceptible to climate change. For example, Pinney and Begét (1991) reported that rapid environmental changes and glacial fluctuations on the Alaska Peninsula might be in response to transient changes in the concentration of atmospheric greenhouse gases and solar intensity. Climate also has a great influence on peatlands, which are found in Katmai's lowlands and lakecountry (Belland and Vitt, 1995). Changes in moisture supply and thermal regime could alter topography and vegetation, which in turn could alter the water surfaces of northern peatlands and thus alter the natural delivery of CO_2 and CH_4 from surface waters to the atmosphere (Rouse et al., 1997). Increases in temperature can also extend ice-free seasons which will usually lead to increases in the ratio of evaporation + evapotranspiration to precipitation, resulting in less water found in the landscape (Schindler, 1997).

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Ecological Profile - Freshwater Ecosystems
Kenai Fjords National Park

Physical Environment

Freshwater Lakes

There are over 150 lakes and ponds in Kenai Fjords National Park (KEFJ) with a combined surface area exceeding 4,200 acres (NPS 1999). Two of the larger lakes in the park, Delight and Desire Lakes, drain into the east arm of Nuka Bay. These and two other small lakes near Bear Glacier appear to be ice marginal lakes, formed in a small valley where terrain slopes toward a glacier.

Bradley Lake (outside the park), which receives its waters from Kachemak and Nuka glaciers, has been developed as a hydroelectric power site. Water is diverted from the headwaters of the park's Nuka River to help power the site. A minimum flow of 5 cubic feet per second (cfs) is maintained in the Nuka River (NPS, 1999),

Freshwater Streams

Freshwater streams on the Kenai Fjords coast tend to be short and very steep. Waterfalls abound, including an 800 foot falls above the North Arm of Nuka Bay. Recent deglaciations have opened up new streams and lakes, which are being colonized by salmon. The most recent example of this is Delectable (Delusion) Lake on the east side of McCarty Fjord, ice-free within the past 40 years. Although the stream is steep, fast and very rocky, red, coho and pink salmon have ascended it to spawn in the lake (York and Milner, 1999)**.** Streams are generally “flashy” in that the flows respond rapidly to rain events, which can be extreme along this coast. Glacial streams, formed of meltwater from grounded and hanging glaciers, also tend to be short, but lower gradient than most of the clear water streams. Sediment loads tend to be higher at the upper ends of fjords, where glacial waters are slow to mix with main Gulf of Alaska waters. Primary glacial streams flow into Nuka Bay, Northwestern Lagoon and Aialik Bay. Glaciers, such as Bear, Dinglestadt and Pederson, have silty lakes at their faces.

Glaciers, Lake Ice and Snow Pack

The Harding Icefield is one of four icefields in Alaska and Canada. During the Pleistocene and probably late Pliocene, the area north of the Gulf of Alaska, the Kenai-Chugach-St. Elias mountains, were covered with ice. Few vestiges of this ice mass remain. The westernmost example is the Harding Icefield, which covers about 720 square miles.

Seven of the approximately 58 glaciers spawned from the Harding Icefield are tidewater glaciers. Glaciers on the Peninsula flow into Kachemak Bay, except Nuka Glacier, which also flows into Nuka Bay on the Gulf of Alaska.

Glacial meltwaters flow into park lands and adjacent waters and significantly affect stream discharge and rates of flow, abiotic factors and consequently biologic productivity. Little is known about KEFJ glacial flow regimes.

Climate

Warm ocean currents flowing through the Gulf of Alaska result in a climate characterized by cool summers and mild winters for the latitude. Divided by the Kenai Mountains, the park lies in both the maritime and transitional Cook Inlet zone.

The coast has a typical maritime climate, with cool rainy summers and snowy, storm driven winters. The occasional calm sunny day is a treat to be savored. Steep mountains rising straight from sea level to over 5000 feet force moisture laden storms to rise, where cooling temperatures and loss of moisture holding capacity cause the clouds to drop massive loads of snow onto the Harding Icefield. It receives 400 inches of snowfall annually and is snow covered year round (NPS 1999). In contrast, mean annual snowfall for the area is approximately 50 inches. Snow cover is predominate at sea level from November to late May and may be found on upper slopes until late August.

Annual precipitation in the maritime zone is about 60 inches with 100 wet days per year and 32 inches of precipitation occurring from mid-July to late-December (NPS 1999). Rainfall is heaviest in Aialik Bay ranging from 45-80 inches during summer months of the 1990 decade, decreasing somewhat along the coast to the west. Aialik Bay frequently gets 3-4 inches of rainfall in one day with August 20, 1993 recording a memorable 10.55 inches.

Biological Resources

Alder stands and Sitka spruce forests begin immediately above the storm tide zone. Alder is a rapid invader in disturbed zones, following avalanche tracks from the alpine down to tide line. Scattered grasses and forbs find a foothold under the shrubs. Alder provides nitrogen for recently de-glaciated soils, enriching the environment for spruce invasion. Sitka spruce appears to move into de-glaciated terrain within 20 years of ice retreat (Rice and Spencer 1990). Recently developed Sitka spruce stands have uniform aged trees with a thin moss ground cover, scattered grasses and shrubs such as salmon berry and *Menziesia*. Older stands, growing through the last glacial maximum, have spruce of varying ages, thick moss ground cover and on the tree limbs, with alder, salmonberry and Devil's club in openings. A Sitka spruce cut down in Palisade Lagoon was over 700 years old and seven feet in diameter at the time of its death in 1990. It appears that there were spruce forest refugia perched in high valleys above the ice. Glacial geologists have sampled interstadial trees in the fjords to help document forest occupation of these areas prior to glacial advance in neoglacial times (Wiles, 1990).

There have been no systematic surveys for freshwater fish. King, chum, coho, pink and sockeye salmon are known to spawn in numerous park streams. Dolly Varden are also known to be in park streams and lakes but their distribution throughout the park isn't well documented. The Resurrection River which borders the Park on the northeast has a run of coho (silver) and chum salmon as well as representatives of the above mentioned species.

The only lakes known to sustain important sport fish resources are Delight, Desire, and Delusion Lakes in McCarty Fjord. These three lakes support large runs of anadromous fish. Subsistence and commercial fisheries occur in these waters. Port Graham owns the lands immediately adjacent to the lakes. Commercial harvests of fish also occur in James Lagoon in McCarty Fjord and Pederson Lagoon in Aialik Bay.

Twenty-two species of terrestrial mammals have been observed on the south coast of the Kenai Peninsula, and 15 others are presumed to inhabit the area. Approximately 65 species of birds, the majority of which are marine or marine-associated, have been reported in the area. Several species of shorebirds are known to utilize the coast of KEFJ. The Black Oystercatcher and Semipalmated Plover are known to nest on pocket beaches tucked in the fjords. Numerous other species are known to breed and migrate through coastal areas of the park. Black Oystercatchers were identified as an "injured species" following the 1989 Exxon Valdez oil spill. AN estimated 3.6% of the population in the spill area were killed during the incident. In 1999, 10 years after the spill, oystercatchers were still not listed on the "recovered" list (NPS, 1999).

There are a few brown bears along the Resurrection River Valley. Black bear are relatively abundant and widely distributed in the area. Black bear appear to be concentrated along fishing streams in the Resurrection River Valley and at drainages to the northwest and south. Black bears are also common along the coast and seem to concentrate in coastal lagoon systems. Other species of terrestrial mammals include wolverine, coyote, lynx, beaver, marmot, marten, vole, and bat.

NPS Natural Resource Inventories and Monitoring

A study documenting stream colonization by invertebrates and salmonids was initiated in Delight, Desire and Delusion Lakes in 1992 (Milner and York, 1999). The study was designed to provide some understanding of ecosystem processes that follow glacier retreat. Park staff made their own invertebrate collections in 1997 in Cloudy Cape Lagoon, but samples have not been identified (KEFJ, 1997).

A brief report on water resources and hydrologic hazards in the Exit Glacier area was produced in 1985 (Sloan). Some limited water chemistry was done in streams below an unpatented mining claim in Nuka Bay and in Delight and Desire Lakes associated with a study of sockeye salmon productivity (Edmundson et al., 1998). Research has been initiated detailing early succession on glacial till: mycorrhizal colonization and patch formation (Helm, 1994).

Human Activities With the Potential to Affect Freshwater Resources

1. **Access**- Corridors of impact exist in KEFJ along the Exit Glacier Road and Harding Icefield trail. Gravel extraction activities and the physical access routes themselves have the potential to alter hydrologic regimes.

2. **Mineral Extraction**- Park lands are fairly secure from new mineral extraction, but the more significant problem are the effects of past activities, particularly in Nuka Bay. Hydrology and vegetation have still not recovered in riparian areas. Reclamation may be required to regain more natural streambed alignment and grade as well as to encourage revegetation or erosion control.

3. **Air Quality**- Although data does not exist from which to evaluate the true impacts of airborne contaminants, KEFJ is probably affected by long range transport of contaminants from the Far East. In addition, local and regional sources of contaminants may be of concern, particularly from oil refineries on the Kenai Peninsula and cruise ship emissions. A chemical plant in Nikiski uses Cook Inlet natural gas as a feedstock to manufacture more than 5,000 tons of fertilizer per day. The plant is the largest fertilizer complex on the West Coast and is a major supplier to the agriculture industry in the Western United States. A gas liquefaction plant at Nikiski, the only one of its type in North America, supplies 1.3 million barrels of liquefied natural gas to Japan each month.

4. **Oil and Gas Exploration, Transport and Production Activities**- Oil transport accidents from tankers travelling from the Port of Valdez have resulted in damage to the KEFJ coast in the past and the potential for a reoccurrence of a large spill are great. Smaller spills resulting from onboard fuel of commercial boats that run

aground or sink and chronic, small spills from boats are yet another form of water borne contamination.

5. **Hazardous Materials and Waste Management-** Hazardous waste on disturbed lands, especially mining claims, could be impacting water resources in the Nuka Bay area of the park. For example, high concentrations of arsenic found at the Beauty Bay mine were stabilized in 1997 by mixing contaminated soils with concrete and placing a concrete cap over the contaminated soils in an old settling pond area. Staff is still in the process of identifying hazards on abandoned mine lands in the park. Contaminated soil remediation at these sites will continue into the future.

   Underground storage tanks are continually a threat to ground and surface waters. The park is working to get all USTs into federal and state compliance, but the threat of undetected spills from old tanks is a concern.

6. **Water Diversion for Bradley Lake Hydroelectric Power-** In June 1986 an agreement was signed with the Alaska Power Authority allowing diversion of melt water off the Nuka Glacier (outside NPS lands) into Bradley Lake for a hydro-electric power project. The agreement stipulates that 5 cfs will flow into the park's Nuka River. A diversion structure regulates the flow from the Nuka Glacier pool.

7. **Recreational Use**. Impacts from recreationists are generally related to camping and fishing activities. Human waste, littering, bank erosion, and fuel spills are all potential sources of contamination.

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Ecological Profile - Freshwater Ecosystems
Lake Clark National Park and Preserve

Physical Environment

Lake Clark National Park and Preserve (LACL) encompasses approximately 4 million acres of public and private lands in southwestern Alaska and contains some of the most diverse water resources in the National Park system. The park and preserve include over 6000 miles of rivers and streams that flow through coastal, glacial, volcanic, and freshwater environments. The pristine headwaters for five major drainage basins are located within LACL's boundaries (the Kvichak River, Nushagak River, Kuskokwim River, Chakachatna River and Coastal basins). The Kvichak River drainage basin is the world's most productive spawning and rearing habitat for sockeye salmon. LACL also includes the sixth largest lake in Alaska, Lake Clark, and three river segments designated as "Wild Rivers": Chilikadrotna (11 miles), Mulchatna (24 miles), and Tlikakila (51 miles) (National Park Service, 1999a).

The Alaska and Aleutian mountain ranges form a continuous watershed divide separating the coast from the interior. LACL's most dominant interior drainage basin is the 3000 mi^2 Lake Clark drainage, which feeds Little Lake Clark, Lake Clark and Six Mile Lake (Brabets, pers. comm., 2000). The Lake Clark drainage is part of the *Kvichak River Basin,* which drains Lake Clark (143 mi^2) and Lake Iliamna, the largest lake in Alaska (1226 mi^2). The 60-mile-wide basin extends northeastward from the northeast tip of Bristol Bay (Kvichak Bay) approximately 170 miles into the northwest slopes of the Aleutian Range. This basin also drains part of Katmai National Park and Preserve (Alagnak Wild River). The *Kuskokwim River Basin* drains the Stony, Necons, and Telaquana rivers, located in the northern portion of Lake Clark National Preserve, into Kuskokwin Bay. This large basin is approximately 500 miles long and averages 100 miles in width. The *Nushagak River Basin* drains the Mulchatna and Chilikadrotna rivers, located along the western portion of LACL, into Bristol Bay and is approximately 220 miles long and 100 miles wide. Along LACL's eastern boundary is the coastal drainage basin, which includes the *Chakachatna River Basin*. Streams along the coast drain the eastern mountain slopes to Cook Inlet (U.S. Department of the Interior, 1952). These coastal drainage basins include the following park drainages: Chilligan River, Igitna River, Neacola River, Drift River, Crescent River, Tuxedni River, Johnson River, and West Glacier Creek.

Freshwater Lakes

Kvichak River Basin Major lakes located within the include Lake Clark, the largest lake and most prominent geographic feature in the park, with a drainage area of 2942 mi^2 (Brabets, pers. comm., 2000). Discharge from Lake Clark varies seasonally from 1060 – 42,370 ft^3/s and is a major water source for the *Kvichak River Basin* (Demory et al., 1964). Glacially-fed Kontrashibuna Lake heads the Tanalian River, which discharges into Lake Clark immediately southwest of Port Alsworth. Portage, Lachbuna and Kijik Lakes are major water sources for the Kijik River. Clear and deep, Portage Lake was the most alkaline (total alkalinity as $CaCO_3$ = 136 mg/L) of the lakes sampled within LACL in 1978 (Alaska Department of Fish and Game and National Park Service, 1980). Although Kijik Lake drops off sharply along its east and west sides, significant littoral areas on the north and south ends provide important salmon spawning habitat. Otter Lake, located on the west side of the Tlikakila River, is a shallow lake with no inlet streams. Its short outlet stream drains into the Tlikakila. The Upper and Lower Tazimina Lakes feed the Tazimina River, where a hydroelectric facility was recently constructed. The two lakes are the catch basins for a 350-mi^2 watershed. The Pickerel Lakes (Upper, Middle, Lower) empty into Sixmile Lake via a short outlet stream. Caribou Lake, located on the western preserve boundary, is one of several small lakes in the headwaters of the Koksetna River. This relatively small lake is primarily fed by snowmelt and springs from nearby alpine tundra hills (Alaska Department of Fish and Game and National Park Service, 1980).

Nushagak River Basin Lakes located in the *Nushagak River Basin* include Turquoise Lake, the initial headwater source for the Mulchatna River. The main inlet stream, which originates from a glacier several miles away, enters the eastern end of the lake. Twin Lakes are the upper watershed source for the Chilikadrotna River. These two lakes occupy a glacial basin and are connected by approximately 0.3 miles of river. Fishtrap Lake is a major water source of the Little Mulchatna and Chilikadrotna rivers. Snipe Lake feeds a small tributary to the Chilikadrotna River (Alaska Department of Fish and Game and National Park Service, 1980).

Kuskokwim River Basin Lakes located in the *Kuskokwim River Basin* include Telaquana Lake, a 16-mi^2 lake that is the principal source of the Telaquana River. This deep lake has littoral habitat in the western and extreme eastern ends (inlet) of the lake. Two Lakes is actually one lake nearly bisected by a spit and is a major source of the Necons River (Alaska Department of Fish and Game and National Park Service, 1980)

Coastal Drainage Basin Two major lakes located within the *Coastal Drainage Basin*, immediately south of the *Chakachatna River Basin*, are Crescent and Hickerson lakes. Crescent Lake is the largest coastal lake in the park. The lake lies in a glacially cut valley that feeds the Crescent River. Hickerson Lake is located on the southeastern slope of Iliamna Volcano. This snow-fed lake does not have a surface outlet (Alaska Department of Fish and Game and National Park Service, 1980).

Table 1. Approximate length, width, and maximum-recorded depth for major lakes located within Lake Clark National Park and Preserve (source: Alaska Department of Game and Fish and National Park Service, 1980 unless otherwise noted).

Lake	Approximate length (miles)	Approximate width (miles)	Max recorded depth 1978-79 (feet)
Lake Clark	40[1]	3.7[1]	1056[2]
Kontrashibuna	13	1.0	ns
Portage	1.25	0.5	170
Lachbuna	2.5	1.0	121
Kijik	2.0	0.75	325
Otter	0.75	Ns	75.5
Upper Tazimina	8.5	0.75	337
Lower Tazimina	7.3	1.8	203
Upper Pickerel	0.75	Ns	62
Middle Pickerel	1.5	Ns	7
Lower Pickerel	2.3	Ns	8
Caribou	0.7	Ns	ns
Turquoise	5.0	1.5	338
Upper Twin	7.0	0.75	275.5
Lower Twin	5	0.5	128
Fishtrap	2.2	Ns	78.5
Snipe	2	0.8	52.5
Telaquana	9.3	2.9	>426.5[3]
Two Lakes	4	1	>174[3]
Crescent	6	2	ns
Hickerson	2.3	Ns	134.5

[1] data source (Donaldson, 1967), [2] data source (Wilkens, 2001), [3] depth exceeded length of survey equipment, ns = not surveyed

Freshwater Streams

Kvichak River Basin Streams located in the *Kvichak River Basin* include the tributaries for Lake Clark. The northeast section of Lake Clark is fed by three principal tributaries: the Tlikakila River [drainage area = 622 mi^2], Chokotonk River [drainage area = 158 mi^2], and Currant Creek [drainage area = 165 mi^2] (Brabets, pers. comm., 2000). These three streams issue from glaciers and constitute approximately 60% (estimated from summer flow data) of the major stream input to Lake Clark (Demory et al., 1964). Portage Creek is a small stream that enters Lake Clark from the north. A placer mining operation several miles upstream of the creek's mouth shows evidence of hydraulic methods (Kucinski, pers. comm., 2000). In 1999, there was a request to start up the mining operation (Knuckles, pers. comm., 2000). The Kijik drainage consists of the Kijik River [drainage area = 298 mi^2 (Brabets, pers. comm., 2000)], a glacial (turbid) stream, and the Little Kijik River, a clearwater stream. The Little Kijik River feeds Kijik Lake before joining the Kijik River. Kijik Lake and the Little Kijik River compose the second largest red salmon spawning area in LACL. The Tanalian River [drainage area = 205 mi^2 (Brabets, pers. comm., 2000)], a glacial stream that passes through Kontrashibuna Lake, enters Lake Clark just southwest of Port Alsworth. Tanalian Falls, approximately 0.5 miles downstream from Kontrashibuna Lake, is an impressive barrier that prevents salmon from migrating further upstream. The Chulitna River [drainage area = 1157 mi^2 drains tundra and lowlands and enters Lake Clark at Chulitna Bay, a large but shallow (10 – 65 ft.) bay. The river is a long (approximately 90 miles) slow flowing stream (1.5 - 2.0 ft/sec) that has a brownish color due to high organic content. In 1999, the U.S. Geological Survey recorded discharges at the mouth of the Chokotonk River, Tlikakila River, Currant Creek, Kijik River, Tanalian River, and Chulitna River (Table 2).

Table 2. Discharge data (ft^3/sec) recorded in 1999 using Acoustic Doppler equipment (Brabets, pers. comm., 2000).

Month 1999	Chokotonk River	Tlikakila River	Currant Creek	Kijik River	Tanalian River	Chulitna River
Mar	ns	25.3	Ns	ns	ns	ns
May	ns	510	Ns	ns	ns	ns
Jun	2190	ns	2670	1750	5920	4090
Jul	1200	ns	1590	857	1620	1400
Aug	1950	5850	1280	1130	1850	4060
Sep	ns	ns	885	758	650	3160
Oct	260	870	278	431	543	2200

Note: each value represents a single measurement collected at each stream mouth during the respective months. ns = not sampled

The Tazimina River connects Upper and Lower Tazimina lakes and enters Sixmile Lake near its outlet, the Newhalen River. The U.S. Geological Survey monitored stream flows on the Newhalen River (Station 15300000) from 1951 to 1967, and from 1982 to 1986. Peak discharge occurs during summer melting of the previous winter's snow and ice.

Nushagak River Basin The *Nushagak River Basin* includes the Chilikadrotna River that originates at Twin Lakes and flows southwesterly for approximately 60 miles before joining the Mulchatna River. Only the river's extreme upper section is included in LACL where mid-channel depths ranged from 3.3 – 8.2 feet and velocity averaged 3.3 ft/sec in 1978. The Mulchatna River originates at Turquoise Lake and flows southwesterly for approximately 217 miles to its confluence with the Nushagak River. In LACL, the river is approximately 50 meters wide with a recorded velocity of 3.3 ft/sec in 1978 as it meanders through a moraine deposit. The river increases in velocity through the Bonanza Hills as the gradient increases to 47 feet/mile (Alaska Department of Fish and Game and National Park Service, 1980).

Kuskokwim River Basin The *Kuskokwim River Basin* includes the Necons River that flows out of Two Lakes and into the Stony River. The Telaquana River drains from Telaquana Lake before joining the Stony River.

Chakachatna River Basin The *Chakachatna River Basin* and the other LACL coastal drainages include all the streams that empty into Cook Inlet. The Neacola, Chilligan, Igitna, and Another rivers flow outside the park through Kenibuna Lake, located on the park's northeastern boundary, and into Chakachamna Lake. Shamrock Glacier terminates in Kenibuna Lake. The outlet for Chakachamna Lake is the Chakachatna River that flows into Cook Inlet or joins the McArthur River before entering Cook Inlet. The Drift River is a braided system that drains the Chigmit Mountains, including Redoubt Volcano, before emptying into Cook Inlet. The Crescent River empties into Cook Inlet just north of Tuxedni Bay, a sensitive salt marsh area. The watershed is currently being logged. The Johnson River drains the glaciers and snowfields on the southeastern slope of Iliamna Volcano.

Wetlands

LACL contains extensive freshwater and saltwater wetlands. Approximately 30-40 percent of LACL may be classified as wetlands (National Park Service, 1999a). At lower elevations (typically < 2500 ft msl), where there is periodic flooding or poor drainage, distinctive wetland ecosystems are common in the park (Racine and Young, 1978).

The park's wetlands represent transitional environments, located between uplands and deepwater areas. Flora within these wetland systems exhibits extreme spatial variability, triggered by very slight changes in elevation. Temporal variability is also great because the surface water depth is highly influenced by changes in precipitation, evaporation and/or infiltration. Racine and Young (1978) described four different wetland ecosystems in LACL: 1) tidal salt marsh, 2) peat bogs, 3) fresh water marsh (bordering small ponds and river valleys), and 4) aquatic (shallow water in ponds and lakes that support aquatic vegetation). The U.S. Fish and Wildlife Service has produced 14 draft wetland maps. The NPS and USFWS have established an interagency agreement to further map and digitize an additional 28 quads (1:40,000 scale) using National Wetlands Inventory mapping conventions (Knuckles, pers. comm., 2001).

Glaciers, Lake Ice, and Snowpack

The hydrologic cycle in the park is influenced in part by extensive glaciers and snowfields that supply vast quantities of silty meltwater to the headwaters of drainage basins during the summer months. Glacial ice, much of it associated with Redoubt and Iliamna volcanoes, covers approximately 30% of the park. Most of the glaciers in the park have retreated dramatically in the last four decades, which indicates that melting is occurring faster than snow accumulation (National Park Service, 1999a).

The snow line in LACL begins between 4000 – 5000 ft msl on the east side of the mountain ranges and approximately 8000 ft msl on the west side (Karlstrom, 1964). The overall absence of advanced forest at the higher elevations allows for little mitigation of runoff waters. Water quality from melt water in LACL is likely influenced by the bedrock (Dale and Stottlemyer, 1986).

Although permafrost is not prevalent in LACL, it is distributed sporadically at considerable depth in isolated areas of predominately fine soils where insulation is high (Chamberlain, 1989). Permafrost can influence the hydrologic cycle. For example, permafrost can impede precipitation from recharging aquifer systems. This could result in a greater surface runoff contribution to lake and stream recharge.

Climate

The Chigmit Mountains divide the subpolar marine climate of Cook Inlet from the continental climate of interior Alaska. Local climatic conditions within these two regimes vary with elevation and the distance from mountains and large bodies of water (National Park Service, 1999a).

The climate on the east side of the mountains (coastal environment) is typically warmer and wetter than the west side. On the eastern side where the coastal lowlands form a wide transition between Cook Inlet and the mountains, the precipitation averages 15 to 20 inches annually. Precipitation increases dramatically, ranging between 40 to 80 inches per year, where the mountains immediately rise from Cook Inlet (LACL southeast coast). Mean coastal air temperature ranges from 10˚F to 32˚F during January, typically the coldest month. Mean temperature for the warmest month, July, ranges from 48˚F to 60˚F (National Park Service, 1983).

Port Alsworth, located west of the Chigmit Mountains, represents inland climate conditions. Annual precipitation at Port Alsworth is approximately 17 inches. Mean air temperature ranges from 12˚F in January to 56˚F in July. From 1960-1981, extreme air temperatures recorded at Port Alsworth were 86˚F and –55˚F (National Park Service, 1983).

Biological Resources

Forty-six species of fish are listed as present or probably present in LACL. The U.S. Bureau of Fisheries first surveyed Lake Clark in 1920. They found Dolly Varden (*Salvelinus malma*) in Kijik Lake, northern pike (*Esox lucius*) in Chulitna River, lake trout (*Salvelinus namaycush*) in Lake Clark, and sockeye salmon (*Oncorhychus nerka*) in Lake Clark and several of its tributaries. Grayling (*Thymallus arcticus*),arctic char (*S. alpinus*), rainbow trout (*O. mykiss)*, burbot (*Lota lota*) and several species of whitefish (*Coregonus* spp.) also occur. These species are widely distributed in the major lake-river systems throughout LACL, however park waters are not considered highly productive for resident species due to low water temperatures and low nutrients (U.S. Department of Interior, 1975). The highest diversity of salmon occurs in coastal watersheds, where five species of salmon spawn.

Sockeye salmon are a keystone species in the Lake Clark aquatic and terrestrial ecosystem. Nutrients from spawned-out salmon carcasses play a crucial role in sustaining the productivity of riparian and lacustrine ecosystems including the perpetuation of future salmon runs (Kline et al. 1990, 1993). Sculpin (*Cottus* sp.), least cisco (*Coregonus sardinella*), lake trout, rainbow trout and burbot all derive nutrients from sockeye salmon in one form or another. Salmon influence the seasonal distribution and abundance of birds and mammals that prey on them. In the interior of the park and preserve, bald eagles (*Haliaeetus leucocephalus*) are exclusively associated with river-lake systems that support salmon. Bears depend on abundant salmon to bolster fat reserves vital to survival during hibernation. Because much of Lake Clark remains ice free until February, salmon carcasses support overwintering bald eagles and are an important food resource for an array of vertebrate predators and scavengers including wolves (*Canis lupus*), coyotes (*C. latrans*), red fox (*Vulpes vulpes*), wolverine (*Gulo gulo*) and lynx (*Lynx canadensis*).

A wide range of fauna, both terrestrial and aquatic, depend on LACL's diverse water resources either directly or indirectly. Inventories of LACL's fauna includes166 bird species, while 45 species of mammals are listed as present or probably present. Waterfowl, shorebirds, gulls and some raptors rely extensively on food and habitat associated with wetlands, lakes and rivers. Many passerine species nest and feed in riparian areas or wetlands. Brown bears (*Ursus arctos*), black bears (*Ursus americanus*), moose (*Alces alces*), small mammals such as voles, lemmings and shrews, and furbearers, such as mink (*Mustela vison*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethica*) and river otter (*Lontra canadensis*), are important links in aquatic ecosystems.

The wood frog (*Rana sylvatica*), the lone amphibian species found LACL, appears to be widely distributed throughout the Lake Clark watershed (Knuckles, pers. com., 2002) but no amphibian surveys have been conducted.

NPS Natural Resource Inventories and Monitoring

Some water quality data within LACL's watersheds are available. Early limnological studies of the aquatic systems that include LACL were of a broad or general nature [Burgner et al. (1969), Mathisen and Poe (1969), Alaska Department of Fish and Game and National Park Service (1980)]. A 3-year study of chemical, physical and biological characteristics of surface waters in the park, [Dale and Stottlemyer (1986), Stottlemyer and Chamberlain (1987), and Chamberlain (1989)], provided more specific water chemistry data on selected surface waters in LACL. The University of Alaska (Fairbanks) recently completed a limnological assessment of Lake Clark (Wilkens, 2001).

Based on the limited data to date, surface water quality in the park appears to be of excellent quality. Highly mineralized areas, active volcanism, and large glaciers contribute to unique natural water quality in the park. For example, chloride and sulfate concentrations exceeded the secondary drinking water criterion of 250 milligrams per liter (mg/L) in the Drift River in April 1990 (870 mg/L and 980 mg/L, respectively) and in Crater Creek near the Redoubt Volcano in October 1991 (330 mg/L and 880 mg/L, respectively). Seven observations near Iliamna, the Tanalian River, and the Drift River were less than or equal to pH 6.5, which is below EPA's chronic criteria for freshwater aquatic life. The lowest pH was reported in the Drift River (pH = 4.0) in April 1990 after the Redoubt eruption (National Park Service, 1997).

Michigan Technological University completed a 3-year water quality study (1985-1987) to acquire baseline data for 15 lakes and rivers. Chamberlain (1989) evaluated the 1985–1987 study and identified some key elements:

> Lake Clark was thermally uniform in June, but during the warmer summer months thermal stratification resulted. Dissolved oxygen was close to saturation. There were two distinct lake turnover periods, June and October, where dissolved oxygen profiles were uniform through the water column. Sediment input has a dramatic effect on light attenuation. It appears that mid-July is the time of peak sediment input to Lake Clark, which originates from glacial meltwater. By August, sediment distribution throughout the lake has occurred, and lake compensation depths (top of lake to bottom of euphotic zone) are reduced. The Tlikakila River contributes, by far, most of the sediment input to Lake Clark. Two other fluvial systems, Currant Creek and Kijik River, also contribute substantial amounts of suspended solids to the lake.
>
> Most lakes in LACL are very low in nitrate concentrations suggesting the basins feeding the lakes have little organic material and low aquatic productivity. Nitrate (NO_3^{-}) was found to be the most common nutrient

limiting primary production in Lake Clark. Phosphate (PO_4^{2-}) also stimulated productivity. Nitrate and phosphate are important seasonally in controlling the productivity in Lake Clark. Natural factors that likely contribute to the variability in nutrient limitation include: sediment inputs, salmon decaying, and thermal stratification

The water temperature and dissolved oxygen of all the smaller lakes studied in LACL were similar to those of Lake Clark. Each of the smaller lakes experienced uniform water temperatures through the water column in the spring and fall, and each was slightly stratified in summer. Dissolved oxygen was always at or near saturation. Light penetration varied widely between and within the smaller lakes studied. Kontrashibuna, Kijik, and Upper and Lower Tazimina lakes remained clear through the sample season, while the remainder of the lakes studied began the summer clear, becoming turbid later in the season. The 1987 light extinction coefficients recorded for Lake Clark were 0.30, 0.35, and 0.65 for June, July, and August, respectively.

USGS-WRD monitored water quality and runoff characteristics for the Tlikakila River and other major Lake Clark tributaries over three runoff seasons, 1999-2001. Although the Tlikakila watershed comprises 21percent of the Lake Clark Basin, it contributes 37 to 47 percent of the total inflow. The river is a calcium to calcium magnesium bicarbonate water type with low buffering capacity. During the study period, it transported between 0.4 to 1.5 million tons of suspended sediment into Lake Clark. The resulting sediment plume makes the lake light-limited in terms of primary productivity. Monthly measurements of flow and water quality were also collected on the Chokotonk River, Chulitna River, Currant Creek, Kijik River and Tanalian River. Discharge measurements at the Lake Clark outlet (Newhalen River) provided additional data to produce a water budget for the lake (Brabets, in press, 2002). In 2001, USGS-WRD collected data on runoff components in the Tlikakila River Basin to determine the relative contributions of springs, glaciers, rainfall and snowmelt. Several airborne profiles of glaciers were flown to help construct a history of glacier change in the Basin. Preliminary results indicate that from 1957 to 1996, the glaciers have been thinning at an average rate of between 0.46 meters/year and 0.96 meters/year. However, the glaciers may be thickening from 1996 to 2001 (Brabets, 2001).

The University of Alaska at Fairbanks initiated a limnology study of Lake Clark in 1999. The purpose of the study was to study the physical and chemical characteristics of Lake Clark to its full depth of 322 meters, and examine the zooplankton species and biomass in cooperation with contemporaneous studies on the tributaries and the sockeye salmon in the lake. The final version of this study will be available through the Alaska Cooperative Fish and Wildlife Research Unit at the University of Alaska at Fairbanks (Wilkens, 2001).

Temperature profiles indicate the lake; (1) does not hard-stratify, and (2) mixes down to between 20 and 50 meters, deeper than was previously thought. Both the epilimnion (uppermost water layer) and hypolimnion (lowermost water layer) are fully oxygenated, probably year-round. Chlorophyll *a* concentration is most closely linked to euphotic depth, as opposed to integrated turbidity.

The fluctuation of total suspended solids is best explained by inorganic suspended solids, with organic solids remaining fairly constant throughout the growing season. A cursory look at the zooplankton data that is available to date indicates that the lake is dominated by cyclopoid Cladocerans, distributed throughout the top 164 ft (50 meters) of the water column.

Some preliminary conclusions are that Lake Clark mixes frequently and deeply, with wind events maintaining high oxygen levels. This would tend to increase the productivity of the lake and partially explains the abundance of sockeye salmon. Inorganic suspended solids have the largest effect on turbidity and euphotic volume, suggesting that; (1) phytoplankton is not self-shading in the lake and (2) the glacially-derived inlet rivers at the north end of the lake drive primary productivity, making the lake light-limited.

The U.S. Bureau of Fisheries conducted the first surveys of Lake Clark in August 1920. Follow-up surveys were conducted in 1921-22, 1924-28, 1931, 1933, 1937-38, 1940, and 1947-49. Accounts of these surveys were published in Reports of the Commissioner of Fisheries to the Secretary of Commerce, Alaska Fishery and Fur Seal Industries. The Alaska Department of Fish and Game conducted a fisheries resource inventory within the proposed LACL boundaries in 1978-1979. The study encompassed 27 lakes and portions of 13 rivers. Information included fish distribution, age and growth, relative abundance, food habits, and spawning area (salmon species). Limited liminological data were also collected (Alaska Department of Fish and Game, 1980).

The U.S. Bureau of Fisheries obtained numerical estimates of sockeye salmon escapement to particular spawning areas during some years of their surveys, but for other years only subjective statements describing apparent run strength appear (i.e., "not as numerous as in previous years"). In 1950 the Fisheries Research Institute (FRI) of the University of Washington began conducting salmon related investigations in the Kvichak River watershed, including the Lake Clark area (Demory et al. 1964). Their efforts were directed primarily at obtaining information on factors affecting sockeye salmon production. Their studies at Lake Clark have included

- bathymetric measurements (Anderson 1969),
- cataloging of sockeye salmon spawning areas including bottom type descriptions and total spawning area (Demory et al., 1964 and Anderson, 1968),
- determination of juvenile sockeye distribution, abundance, age, and growth (Orrell 1963 and Kerns 1968), and;

- compilation of annual indices of sockeye escapement (Demory et al. 1964; Anderson 1968; Anderson and Poe 1969).

Recent studies have focused on feeding competition between sockeye salmon pre-smolts and least cisco (*Coregonus sardinella*) (C. Foote pers comm.).

Since 1999, USGS-Biological Resources Division, along with a number of cooperators, has been investigating various aspects of sockeye salmon ecology throughout the Lake Clark watershed. Studies are still ongoing and include genetic diversity, population abundance and trends, salmon movement patterns, and location and characterization of spawning sites. Preliminary results indicate that Lake Clark salmon are genetically distinct from other Kvichak River and Bristol Bay populations. Dramatic declines in salmon escapement have continued to occur since 1996, with an estimated 221,418 fish (20% of the estimated Kvichak escapement) counted in the Newhalen River in 2001. Discharge measurements for the Newhalen River demonstrated the effects of a velocity barrier to fish passage, which delayed run timing in 2001(Woody, 2001).

Salmon radiotagged as they entered Lake Clark yielded new data on contemporary migration paths and spawning distributions. Lake Clark salmon show an unusually high affinity for lakeshore spawning sites (Woody, pers. comm., 2002). Remote temperature sensing units have been deployed at 14 spawning locations to monitor incubation temperature. Woody and Young are collecting data on basic habitat characteristics and determining fluvial process groups for spawning sites (Young and Woody, 2001).

Long term changes in salmon abundance are being determined through lake bottom sediment core analysis. Salmon transport nutrients, including nitrogen isotopes (^{15}N), from the ocean to freshwater spawning sites. ^{15}N released after death accumulates in lake bottom sediments, which can be used to determine fluctuations in salmon abundance throughout prehistory (Woody, 2002).

While most studies have focused on Lake Clark, water quality data have also been collected at Johnson River, a coastal watershed explored in the 1980’s and early 1990’s for potential mineral extraction. During 1998-2001, Johnson River was included in the Cook Inlet National Water Quality Assessment Program. USGS operated a streamgage year round near the ore deposit site. These data provided a good overview of spring baseflow, snowmelt, and summer runoff conditions. Eighteen water samples (6 per year) were collected and analyzed for a number of constituents such as nutrients, trace elements, organic carbon, major ions, and suspended sediment. About 60 rock samples were collected near the ore deposit and analyzed for trace elements and their potential for acid mine drainage. Preliminary results indicate good water quality and a 'low acid-generating potential/high neutralizing potential' of the ore deposit (Brabets, 2001).

Human-related Activities With the Potential to Affect Freshwater Resources

1. **Air Quality**. Poor air quality can degrade water resources and aquatic communities. Quantitative air quality data are limited throughout Alaska and currently no baseline air quality data exist for LACL (National Park Service, 1999a). As previously discussed, the park includes environments extremely susceptible to contaminants because of poor buffering geology. Also, recent research has indicated that small increases in nitrogen can have significant impacts in nutrient-poor environments such as LACL (National Park Service, 1999a). Thus, airborne contaminants such as ammonium nitrate or nitric acid could significantly degrade water quality and alter aquatic communities in the park. Numerous sources for airborne contamination exist in the Lake Clark region including emissions from offshore oil/gas development in Cook Inlet and coal extraction at the Beluga coal fields northeast of the park. Without active air monitoring, LACL does not know what impact(s), if any, airborne contaminants contribute to the park's natural system, or how the current water quality correlates to air quality.

2. **Climate Change**. LACL's environment is thought to be very susceptible to climate change. Brabets (2001) reported that glaciers in the Tlikakila River Basin have been thinning at the average rate between 1.51 ft/year (0.46 m/year) and 3.15 ft/year (0.96 m/year) from 1957 and 1996.

3. **Commercial and Private Developments.**
   Mining- Under the Alaska Native Claims Settlement Act of 1976 (ANCSA), the Cook Inlet Region Corporation (CIRI) received title to approximately 21,000 acres of land known as the "Johnson River Tract" located on the west side of Cook Inlet in LACL. The Johnson River headwaters have the potential to become the largest commercial mining operation within an Alaskan park. Based on the current size estimate of the ore body, approximately 270,000 tons of ore would be mined and transported annually over a 3-year mine life (National Park Service, 1999a). Due to the proximity of the planned mine and support network of roads and ore stockpiles to the Johnson River, there is a high potential for contaminants to reach the Johnson River estuary and be transported along the coastline by prevailing tidal currents (Bennett, 1996).

   To provide some baseline information for this high-profile area, the U.S. Geological Survey and NPS are collecting geochemical data from the Johnson River watershed and monitoring Johnson River discharge at a telemetered gaging station.

   There are other potential mining activities in the region that also pose natural resource concerns for LACL. For example, Cominco, an international mining corporation, has filed state mining claims on the Pebble/Copper deposit north of Lake Iliamna. If developed, this open pit mine would be the largest in Alaska. Although development would occur 15 miles southwest of LACL, direct impacts on air and water quality may have substantial effects on park resources (National Park Service, 1999a).

Logging- The Circle DE Pacific Corporation received approval to conduct timber harvesting activities on three cutting units (approximately 2,403 acres) along LACL's coast in Tuxedni Bay within the Crescent River watershed. Timber in these units has been infested extensively by the spruce bark beetle, leaving large stands of dead trees. The lands are owned by Ninilchik Native Association and Seldovia Native Association. A total of 10 million board feet of lumber (white spruce) are proposed for removal from the forested areas (National Park Service, 1999a).

Approximately three miles of primary roads and six miles of secondary roads were built in 1998. During 2001-2002, about 700 acres of land were logged. The primary access road was extended to the Crescent River, more secondary roads constructed and bridge sections hauled to the river's edge. Bridge construction has been temporarily delayed and the timber company ordered to restore damage to the river channel due to non-compliance with state permitting regulations (Knuckles, pers. comm., 2002).

Hydroelectric Development- The Iliamna-Newhalen-Nondalton Electric Corporation operates a 700 kW facility at Tazimina River mile 9.5 on lands owned by the Iliamna Natives Limited and the Bristol Bay Corporation (HDR Engineering, Inc., 1992). The hydroelectric facility consists of an intake structure, penstock (430 ft. long, 60-inch diameter), powerhouse, and tailrace, with a buried transmission line (24.9 kV) that follows a 9-mile access road. The hydroelectric design uses natural "run-of-the-river" flows to power the turbines, which should create no noticeable effects in the Tazimina River flow regime, except between the intake and tailrace. At this location, approximately 4% to 10% of flows are diverted from the river between the months of June and October. During winter low flow months of November through May, between 10% to 100% of the river flow is diverted. The facility was designed to have minimal, if any, impact to river discharge, alkalinity, pH, free carbon dioxide, or dissolved oxygen downstream from the powerhouse [Williams (1995); HDR Engineering, Inc. (1995)].

Residential development- Residential subdivision and economic development on private lands within LACL's boundary can conflict with the park's enabling legislation and NPS management objectives. About 617,000 acres are in private or state ownership, or are being adjudicated. This includes approximately 75% of Lake Clark's shoreline and more than 90% of the park coastline along Cook Inlet. The exact land status is clouded by over-selection, selection by more than one entity, and the incomplete adjudication of many small tract entries and allotments (National Park Service, 1999a).

Many private owners have purchased or settled on tracts to live seasonally or year-round, to pursue a subsistence lifestyle, to access hunting and fishing areas, or to own and manage lodges for visitors. ANILCA allows subsistence harvest of fish, wildlife, wood, and plants in the park, and sport hunting and trapping in the preserve. Some landowners have developed airstrips, small roads and all-terrain vehicle trails on their properties (National Park Service, 1999a).

The population of Port Alsworth has more than doubled over the past 10 years. Other locations such as Keyes Point and Hornberger's Heights support 25-50 residents seasonally (National Park Service, 1999a). Tanalian Incorporated owns 638 acres of land adjacent to Port Alsworth, Hardenburg Bay, and Tanalian Mountain (between the mountain and Lake Clark). Tanalian Incorporated owns an additional 3108 acres just south of the Tanalian River. The corporation has had long standing plans to subdivide these parcels into residential lots (3-acre minimum size) (Knuckles, pers. comm., 2000).

4. **Commercial Fishing-** The number of adult salmon returning to this watershed has declined in recent years and in 1996 was 75% below the previous 10-year average. Commercial fishing of mixed stocks of sockeye salmon, such as occurs in the Bristol Bay Naknek-Kvichak Commercial Fishing District has the potential to overharvest or eliminate small populations (Willson and Halupka, 1995). Commercial fishing regulations are based on the estimated ability of the largest or most productive local stocks to sustain the harvest (Burgner, 1991). This management strategy is economically expedient but tacitly accepts that smaller stocks, such as those which originate in the Lake Clark watershed, may be overexploited.

   The ecological significance of sockeye salmon in the Lake Clark watershed is magnified by their wide spatial distribution. Sockeye salmon occur from the Tazimina River, a tributary on the lower southeast end of the lake, to the upper reaches of the Tlikakila River in Lake Clark Pass, a distance of 170 km. Sockeye salmon have a strong homing tendency, which over evolutionary history leds to the development of locally-adapted populations, or stocks (Ricker 1972; Wilmot and Burger, 1985). Stocks are fish spawning in a particular lake or stream, or portion of it, at a particular season that do not interbreed with any group spawning in a different place, or in the same place at a different season (Ricker, 1972). Due to the mix of glacial and clear-water aquatic habitats within this vast system, genetic differentiation is likely (Wood, 1995). The occurrence of stocks would have broad implications for the protection and management of sockeye salmon in this system. Genetic variation provides the long-term adaptive potential for a population and species. For instance, collapse of stocks in one or more tributaries will reduce the long-term viability of the Lake Clark run and alter the foraging ecology of salmon consumers.

5. **Sport and Subsistence Fishing-** The NPS estimates that about 1,600 sport hunting days, 3,500 angler days, and 30 to 35 river trips occur in LACL annually

(National Park Service, 1999a). There are 39 commercial operators who currently offer “guided sportsfishing” activities in LACL. Along with guided sportsfishing, there are 15 other “guided commercial” services (e.g., air taxi service, photography guide, kayak touring, charter boat, etc.) offered in LACL. As of April 2000, LACL contained 72 commercial operators (Brock, pers. comm., 2000).

Sightseers, anglers, and hunters routinely fly or boat into LACL to take advantage of the park’s pristine natural resources. With an increase in visitor use comes an increase in resource impacts. For example, the recreational demands by freshwater anglers in southwestern Alaska have more than doubled over the past decade. Today, jet-driven boats are becoming more popular in Alaska because of their shallow draft. Shallow headwaters are preferred by Pacific salmon (*Oncorhynchus*) and rainbow trout (*Salmo gairdneri*) as sites of egg deposition for reproduction. Based on a 1992-1993 study by the University of Alaska at Fairbanks, jet boat operation can lead to significant salmonid embryo mortality through mechanical shock, intrusion of fine sediments into the gravel affecting eggs that remain in redds, and the removal of gravel covering eggs in redds with subsequent washing away of eggs (Horton, 1994).

Sport and subsistence fish harvests remove an unknown but increasing number of trout and salmon throughout the park and preserve. Trout and char are apex predators in these freshwater systems and depletion of their numbers may have a cascading effect on predator-prey balance and trophic structure of lakes and rivers. Sockeye salmon affiliated with Lake Clark return to Bristol Bay and migrate up the Kvichak River, cross Lake Iliamna, and travel the length of the Newhalen River before entering Sixmile Lake and Lake Clark, a distance of 150 km. This migratory path exposes salmon to a gauntlet of sport and subsistence harvest. The number of subsistence fishing permits issued for this system has tripled during the past 10 years.

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